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Priorities, Organization, and Sources of Information Accessed by Pilots in Various Phases of Flight

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16. Abstract

In the first project of the study, 27 pilots rated the priority of information required for flight. These pilots were divided by flight experience into novices (65 to 820 hours' flight time) and experienced pilots (1600 to 17,000 hours' flight time). Participants rated 29 information elements across seven phases of flight. These data show the shifting priorities of information across phases of flight, and some clear differences in priority assignments appeared between the novices and the experienced pilots. In the second project, 34 pilots, some from Project 1, participated in the collection of relatedness data for 231 pairs of information elements. A Pathfinder analysis and hierarchical clustering were conducted showing connections among these elements and grouping of the elements. Pilot experience had little influence on the form of the network of associations. The discussion explores the potential of these data for instrumentation layout and integration of cockpit information systems, datalink design, and development of flight instruction curricula.

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TABLE OF CONTENTS

List of Figures

List of Tables

EXECUTIVE SUMMARY

The Aviation Research Group (ARG) in the Department of Psychology at New Mexico State University (NMSU) has research interests relating to several aspects of the organization and display of information in the cockpit. In this report, we present a systematic analysis of the information required by pilots in various phases of flight. Our aim is to specify what information is needed, when it is needed, and how pilots conceive of the organization of the information. This project was devoted to an analysis of the information required in normal flight operations as contrasted with unusual or emergency situations. In future work, we plan to conduct a similar study of information requirements in various emergencies.

The nature of the present study is largely descriptive in that it provides numerous analyses of the priorities pilots assign to different information elements. The study required the development of various taxonomies including: (a) Information used in flight and planning, (b) Phases of flight, and (c) Sources of information used in flight. The analyses show overall priorities of the information elements in various phases of flight and how these priorities compare for more- versus less-experienced pilots. Not surprisingly, priorities change over the course of a flight, and we proposed that the design of new displays would benefit from considering these changing priorities. We also present data on how pilots conceive of the organization of the various elements of information. These data, too, can assist display designers in layout of information.

The differences in information priorities as a function of flying experience identify some issues that flight instructors should consider in flight training. Overall, more experienced pilots tend to give higher priorities to several information elements as though they are considering more factors with higher priority. In particular phases of flight, less experienced pilots give lower priority to communications both with ATC and with traffic than do more experienced pilots. The less experienced pilots assign higher priority to vertical velocity than do more experienced pilots. A discussion of these differences and others can be found in the report.

Our analysis of the sources of information required in flight shows the dramatic impact of GPS technology on aviation. The analysis of sources also allows a determination of the degree to which redundant information is available. Clearly, safety may be compromised when information is only available from a single source.

Modern aviation is undergoing several dramatic changes that affect nearly every aspect of aircraft operating in the national airspace system. Among these changes are: (a) the move to "Free Flight," (b) the development of new control systems for aircraft, (c) development of new information displays and methods for selecting displays, and (d) changes in processes and policies of aviation-related organizations. As these changes come about and as an aid in planning, it is valuable to have models that can help analyze the effect of the changes on critical issues of safety, automation, workload, and situation awareness. We have presented a pilot-centered model of information requirements in flight tasks emphasizing the source, priority, and mental organization of the information elements. This model should allow one to make informed decisions about the design of new technology including information displays. The model should also be useful for evaluating the effect of changes in the airspace system by providing baseline information about where pilots can obtain information in the current system and by reminding policy makers about what information pilots need and when they need it.

Priorities, Organization, and Sources of Information Accessed by Pilots in Various Phases of Flight

INTRODUCTION

This report summarizes the research accomplishments for a one-year project investigating the priorities pilots assign to different information in various phases of flight under normal operating conditions. We use the term, *information*, to emphasize our focus on *interpreted* data, in contrast to raw data. For example, when we refer to information about Traffic, we mean the knowledge that aircraft traffic is present in some particular position rather than the particular data that leads to the knowledge. Thus, our analysis is directed at a cognitive level in contrast to a concern with perceptual processes. The term, *information elements*, is used to refer to the knowledge pilots come to possess (or should possess) during the course of flight. An understanding of how pilots prioritize and organize flight-related information can be of value in the design of display systems for pilots. The data presented in this report can also help characterize what information pilots need as we attempt to characterize the nature of the National Airspace System. This introductory section will provide the rationale for the research effort, as well as background for the research.

Motivation

There were several motivations for us to undertake the research reported here. First, a characterization of information priorities related to various phases of flight together with an analysis of the mental organization associated with the information would be useful in the *design* of new displays for aircraft. Those displays could then be organized to present only the most salient information for any given phase of flight and in a well-integrated fashion, reduce the cognitive requirements, and thus the workload, imposed on the pilot. The end result should be that the pilot can devote more effort to other tasks not directly associated with extracting information from cockpit displays. Second, this approach may provide *an alternative to traditional task analysis* by examining operator perceptions and cognitive organizations of data. Third, identifying the priorities of information should allow us to characterize how pilots view information needs in the current National Airspace System, and to derive from that how changes in the use of that airspace or the allocation of tasks between actors in the system may change perceived priorities. This should then have an influence on how future displays are designed to best support any new tasks or tasks performed in an altered airspace environment.

Display Design

As modern aviation adopts new technology for the display of information and the control of aircraft systems, there is a clear shift away from individual dedicated displays (e.g., altimeter, airspeed indicator, turn-and-bank indicator) toward integrated displays in which most information comes from a common source such as panel-mounted cathode-ray tubes (CRT's), head-up displays (HUDs), or helmet-mounted displays (HMDs). Some critical issues in the design and engineering of such displays concern the decisions about what information to display at any given time, as well as how to display it.

Design decisions about what to display at what times would benefit considerably from a thorough analysis of the various required elements of information (aircraft position, weather, engine status, communications, etc.) and their properties (priority of the information, source of the information, quality of the information, etc.) in various phases of flight. Together with data revealing how pilots organize these information elements, the analysis can assist efforts toward integration in displays and prioritization and layering of information elements. For example, displays designed so that critical information is available when needed in a practical format should be of great assistance to the pilot who is actively controlling the aircraft. Andre and Wickens (1991) demonstrated the ability of an integrated three-dimensional cockpit display system to reduce mental workload while increasing situation awareness. Well-designed displays should also help establish and maintain the pilot's situational awareness

when automated systems are in control. Research on mode errors and mode awareness in supervisory control (Sarter & Woods, 1992) indicates that the increased capabilities and autonomy of new automated systems have made mode awareness problems more prevalent in the modern cockpit.

Comparison With Task Analysis

A long-standing goal in the analysis of aircraft systems is to produce thorough analyses of the tasks involved in flying aircraft and the information required to perform the tasks (Alexander C. Williams, Jr. in Roscoe, 1980). Although the analysis we propose to perform is related to task analysis, it is also distinct in some important ways. In the usual approaches to task analysis, goal-directed activities are analyzed in terms of goals to be accomplished and the actions required to accomplish those goals (cf. Sutcliffe, 1997). A limitation of this approach in the context of aviation is that the actions required of a pilot to accomplish goals are largely determined by the nature of the technology in the aircraft so, in essence, every aircraft calls for a distinct task analysis. Of course, by abstracting the actions somewhat, one could reduce the number of distinct task analyses required, but abstracting would often move the analysis from the task per se toward the goals of the tasks. For example, we could use "put in 10 degrees of flaps" instead of "move the flap control to the 10 degrees mark," but in doing so, we have technically moved from specifying an action to specifying a goal (or, better, a subgoal). It seems clear that goals do remain more constant across technological differences than actions do. Even with extreme degrees of automation in aircraft, most goals of flight remain the same as they were with pilots in control throughout the flight[1]. Still, we should be able to provide a more thorough analysis of the various phases of flight than simply specifying the goals (and subgoals) of each phase and still have some generality across technologies.

Our approach assumes that goals remain relatively constant across technological changes, and the critical information pertaining to flight also remains relatively constant. For the pilot actively controlling the aircraft, it is obvious that particular information elements are critically important at different times in a flight, but it is also true that even when the aircraft is being flown by automated systems, the same information elements are critical. Moreover, for pilots to maintain (or to quickly attain) good situational awareness, they must have these critical information elements whether they are actively in control or not. We also propose that pilots' mental models of flight depend upon having the appropriate information elements. When the pilot's model contains incorrect information, "pilot error" is not far behind.

Evaluating Changes in the National Airspace System

Another application of the data we report is found in its potential for assisting in the analysis of the consequences of changes in the National Airspace System. Our analysis identifies the critical information elements for the various phases of flight. Given these data, it is reasonable to ask about how access to this critical information will be affected by any change in the system. If a proposed change in the system eliminates certain information, our analysis should help to determine whether that information is usually used and, if so, alternative sources of the information could be sought. Studies could then determine whether the alternatives are adequate or whether new options should be considered. In summary, we see our model as providing baseline information about the current state of the National Airspace System that will be useful in planning.

General Plan of the Investigation

The research team consisted of several pilots and student assistants in the Aviation Research Group (ARG) at New Mexico State University, including two pilot consultants. The decisions about materials and taxonomies were made by consulting with the pilots on the research team. The research involved three distinct projects:

Project 1. Selecting particular phases of flight, developing a taxonomy of information elements accessed during these phases, developing a taxonomy of information sources, and identifying the sources of each information element.

Project 2. Collecting priority ratings from pilots for each information element in each phase of flight.

Project 3. Collecting relatedness ratings from pilots for a subset of the information elements to allow for an analysis of the organization of the information elements.

[1] There are clear exceptions where certain goals cannot be preserved with automation as with the goal of realizing the pleasure of flying well.

Project 1: Phases of Flight, Information Elements, and Information Sources

The ARG team developed initial taxonomies of phases of flight, the information elements accessed in these phases, and the sources of these information elements in the National Airspace System. The taxonomies were refined by discussions with pilots resulting in the final products.

The phases of flight are shown in Table 1. To make the project manageable within the one-year period for the work, we initially decided to restrict our work to flying phases, as contrasted with ground phases. The major concerns of safety lie in the flying phases. However, it became clear that it was also necessary to include some planning phases, as well as flying phases, because preliminary testing suggested that pilots want to include considerations of planning. If separate planning phases are not specified, considerations of planning will be included in flying phases. To keep planning and flying distinct, it was decided to include two planning phases, Preflight and In-Flight Planning, in addition to flying phases. In-Flight Planning was included to keep needed planning information distinct from information used in flying, particularly in the Cruise Phase.

The flying phases we included are those found in most discussions of the phases of flight. The Transition to Cruise Phase was included to keep the information used there distinct from the Climb and the Cruise Phases. In contrast, the Transition to Descent was not included because our pilot consultants thought that the transition was not that distinct from the Descent itself. Finally, the analysis was restricted to normal operations, as distinct from emergencies, to keep the project manageable in the time frame. A follow-on study will conduct a similar analysis of various emergencies.

Table 2 was arrived at after performing a preliminary analysis of the information required in normal flight operations. To keep the number of elements manageable, some of the items represent large categories of elements (e.g., Aircraft Configuration, Engine Health, Airport Configuration, General Weather). Other elements refer to very specific items, such as Pitch, Bank, Airspeed, and Altitude. The choice of these elements is intended to be appropriate for evaluating information priorities in the various phases of flight.

Sources of Information in the Current Airspace System

To help relate our analyses of information requirements to the state of the National Airspace System, we also undertook an analysis of how pilots obtain the information they need in flight. First the taxonomy of information sources shown in Table 3 was developed. The sources distinguish major categories of information sources (Communications, Documents,

Table 1. Phases of flight.

Phases of Flight	Percent of Flight Time	Percent of Accidents[2]
Pre-flight Planning	NA	NA
Takeoff	2%	21.4%
Climb	13%	8.8%
Transition to Cruise	(no data)	(no data)
Cruise	60%	8.8%
In-flight Planning	NA	NA
Descent	10%	13.4%
Approach	14%	41.8%
Landing	1%	3.8%

[2] The statistics on percent of flight time and percent of accidents come from a 1985 report by Boeing reported in Nagel (1988). This report distinguished between Initial Climb and Climb. Percentages shown combine Initial Climb with Takeoff. The report also distinguished between Initial Approach and Final Approach, whereas percentages shown combine these into Approach. The statistics may be more representative of air carrier aviation than of general aviation.

Table 2. Taxonomy of 29 information elements.

Aircraft	Expanded Description of each Element
Configuration	
Aircraft configuration	Flaps, landing gear, cowl flaps, speed brakes, spoilers
Engine	
Engine health	General health of engines
Fuel quantity	Fuel remaining
Fuel selection	Current selected source of fuel
RPM (power)	Power setting or desired power
Position	
Altitude - AGL	Altitude above ground level
Altitude - MSL	Altitude above Mean Sea Level
Distance	Distance to waypoint or airport
Orientation	
Bank	Bank
Pitch (attitude)	Pitch
Yaw	Yaw
Direction	
Course	Desired track - Planned course
Heading	Nose direction
Track	Actual track over the ground
Waypoints	Location and type of enroute waypoints
Speed	
Airspeed	Indicated airspeed
Ground speed	Actual speed over the ground
Vertical velocity	Climb rate or descent rate
Schedule	
Time - ETA/ETE	Estimated time of arrival / Estimated time enroute
Environment	
Airport	
Airport configuration	Altitude, runways, approaches, NOTAMs, active runway
Runway aim point	Desired point of touchdown
Runway remaining	Length of remaining runway on takeoff or landing
Communications	
ATC Comm	ATC instructions, clearances, etc.
Traffic / other Comm	Communication with traffic or other information source
Hazards	
Obstructions	Towers, trees, mountains, etc.
Traffic	Other aircraft
Regulations	
Airspace	Type of airspace A B C D, restricted, MOA etc.
Weather	
General	General weather conditions
Wind	Wind direction and intensity

Table 3. Taxonomy of sources of information needed in flight.

Communications	
ATC	Air Traffic Control Communications
Comm	Other (Flight Service, Traffic, ATIS, etc.)
Documents	
Chart	Charts
Hist	History (Aircraft or Flight)
Plan	Flight Plan
Instruments	
ASI	Airspeed Indicator
AI	Attitude Indicator (Artificial Horizon)
ALT	Altimeter
TC	Turn Coordinator
HI	Heading Indicator
VSI	Vertical Speed Indicator
Eng I.	Engine & Fuel (RPM, Oil Pressure, Temperature, etc.)
Clock	Clock
DME	Distance Measuring Equipment
GPS	Global Positioning System
VOR	VHF Omnidirectional Radio Range
Direct Perception	
Aud	Auditory (Excluding Communications)
Vis	Visual (Excluding Reading Instruments)

Instruments, and Direct Perception). For each of the information elements (Table 2), we identified the sources that can provide the information. These resulting sources for each information element are shown in Table 4. The sources of information are distinguished according to whether the information is directly available (D), available through inference using multiple sources of information and/or assumptions (I), or is planning information producing desired or expected values (P). Clearly, direct information is more readily available and immediately usable than is information that must be inferred. Thus, one view of Table 4 might emphasize the "D" entries.

Several observations can be made about the outcome of the analysis of information sources shown in Table 4. First, the observation that much of the information is available from direct visual perception (not counting reading instruments) brings home the point that, without visual conditions, flight is a strikingly different activity. The potential differences between instrument meteorological conditions (IMC) and visual meteorological conditions (VMC) are also dramatized by the number of different information elements available from ATC. The table also reveals redundancy in information sources. Safety is certainly enhanced by the availability of alternate sources of information in case one source should fail. Finally, the ubiquity of GPS as an information source suggests that this technology is destined to become a major resource in the future if it hasn't already. As others in the human factors and pilot communities have noted, there are problems of over reliance, over confidence, and lack of familiarity with particular GPS units that can lead to dangerous situations. At the same time, the value of the information provided by GPS systems can greatly simplify tasks of navigating leading to lower workload. Making the system work well and making it reliable and usable are challenges for pilots, manufacturers, and researchers.

Project 2: The Priorities of the Information Elements in Various Phases of Flight

During development of the priority-rating task, we considered distinguishing between visual and instrument flight for some of the properties of information elements because the sources of information often depend on this distinction. Our initial tests, however, indicated that the differences were minor, so we simply asked for general priorities.

Following the selection of the phases of flight and the development of the taxonomy of information elements, we began to collect the priority rating data by distributing questionnaires at several sites around the country. The details of this methodology are provided in the following sections.

METHOD

Participants

Twenty-seven certified pilots of varying age and experience were used as sources for the priority rating data. To examine the effect of experience on judgments of priorities, we separated the pilots into two groups based on their total flying time. The hours of the 11 less experienced pilots (novices) ranged from 65 to 820 with a mean of 361 and a standard deviation of 225. The 16 more experienced pilots (experienced) had a range of flying time from 1,600 to 17,000 hours with a mean of 6,634 and a standard deviation of 4,352. Fifty-four percent of the less experienced pilots held the Instrument Rating, while 88% of the more experienced pilots were instrument rated.

Table 4. Sources of the information elements in the National Airspace System.

Information Element	ATC	Comm	Chart	Hist	Plan	ASI	AI	ALT	TC	HI	VSI	Eng Inst	Clock	DME	GPS	VOR	Aud	Vis
Aircraft Config.	D	D																D
Engine Health				P								D					D	D
Fuel Quantity					P							D						
Fuel Selection																		
Power											I	D					D	
Altitude - AGL	DP		P		P													D
Altitude - MSL	DP		P		P			D							D			
Distance	DP	P	DP	I	P								I	D	D			D
Bank							D		DI	I								D
Pitch						I	D	I			I							D
Yaw									D									I
Course	DP	P	DP	I	P					I					DP	D		D
Heading	DIP				P		I			D					I	I		D
Track	DP		P	P	P		I			I					D	I		D
Waypoints	P		IP	P	P								I	D	DP	D		D
Airspeed	I				P	D									I		I	
Groundspeed	DP			I	P	I							I	D	D	I		D
Vertical Velocity	DP			I	P	I	I	I			D							D
Time - ETA/ETE	DP			I	P								D	D	D			
Airport Config.	DP	D		DP	D										D			D
Runway Aimpt.			P		D										P			D
Runway Remain.			D	DP	D										D			D
Obstructions	DP	DP	D	DP	D										D			D
Traffic	D	DP																D
Airspace	DP		D	DP	D									D	D	D		
General Weather	DP	DP			P													D
Wind	DP	DP			P									I	I	I		I

Note. D = Directly obtained (current) values
I = Inferred (current) values using multiple sources
P = Planned or expected values

Materials

The priority rating data were collected using a questionnaire that included demographic information (Appendix A), a definition of the information elements (Table 2), instructions for the priority ratings (Appendix B), and a form listing the information elements on the rows, the phases of flight on the columns and cells for assigning the priority ratings for each information element in each phase of flight (Appendix B). The definition of the priority ratings is shown in Table 5. The cells left blank were coded as 4 (lowest priority) for analysis of the priority scores.

Table 5. Definition of the priority ratings.

Priority	Description
1	Critical and/or Frequently Accessed
2	Important and/or Usually Accessed
3	Relevant and/or Sometimes Accessed
blank	Not Relevant or Rarely Accessed

Note. Blanks were coded as 4 for analysis.

Design and Procedure

Collection of the priority data occurred over an eight-month period. The participants were given the priority-rating packet and a stamped, addressed envelope. Upon completion, the participants returned the demographic information and the priority ratings through the mail.

RESULTS AND DISCUSSION

Overall Priorities for Phases of Flight and Information Elements

The priority rating data lends itself to several different analyses. One way to examine these ratings is to average them across information sources within a phase of flight, the result reflecting how many sources of information were rated as being critical during that phase. The average would approach 1 as more sources were rated "critical." The average priority ratings for each phase of flight are shown in Figure 1[3].

By way of comparison, the mean priority ratings were 2.45 and 2.35 for Preflight Planning and Inflight Planning, respectively. For the flying phases,

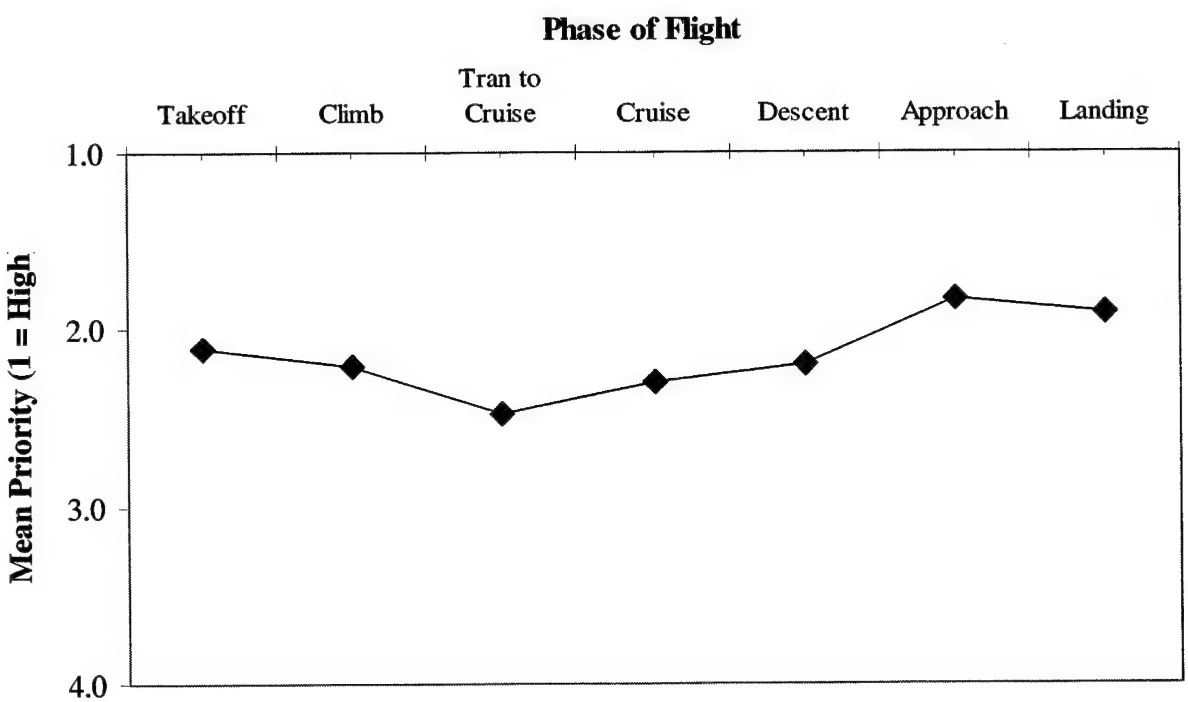

Figure 1. Mean priority for flying phases.

[3] This figure and several others have lines connecting the points. Strictly speaking, the lines are inappropriate because the abscissa represents discrete points rather than a continuum. However, the addition of lines facilitates reading the figures. Think of the lines as leading the eye from point to point, rather than as an interpolation between points.

the highest average priority ratings were for the Approach, followed by the Landing, Takeoff, Descent, Climb, Cruise, and Transition to Cruise. Climb and Descent had nearly identical means. This ordering of priority ratings appears to roughly correspond to what pilots often report as the relative difficulty of the different phases of flight. In a later section, we discuss the relationship between priorities and workload.

It is also of interest to examine how the priority ratings were distributed across the four categories (1 = top priority to 4 = irrelevant or rarely accessed). The distributions are shown in Figure 2. The figure shows the proportion of each of the 4 rating categories in each phase of flight. The proportions sum to 1 for each phase. These distributions show that the overall higher average priorities in the more demanding phases of flight are primarily due to an increase in the proportion of information elements receiving the highest priority rating. These data also suggest that the 3rd category (Relevant and/or Sometimes Accessed) is not used very often. However, its frequency does increase in the less demanding phases of flight where, presumably, pilots are monitoring several factors on an occasional schedule.

In addition to looking at priorities for phases of flight, it is informative to see how priorities are assigned to the information elements overall. The overall averages are shown in Table 6 with separate columns for the flying phases and the planning phases. There are clear differences in the priorities associated with planning and with flying. Of course, we need to examine the information priorities separately for each of the phases, but the overall priorities give a general idea of which items of information are of interest throughout a flight (those at the top of the list). The planning priorities reflect the relative importance of the different information elements. Proper planning should include special consideration of the high-priority items. Items at the end of the list may be important in particular phases but not overall. For example, Runway Remaining has an average priority near 1 in Landing, in contrast to near 4 in Cruise.

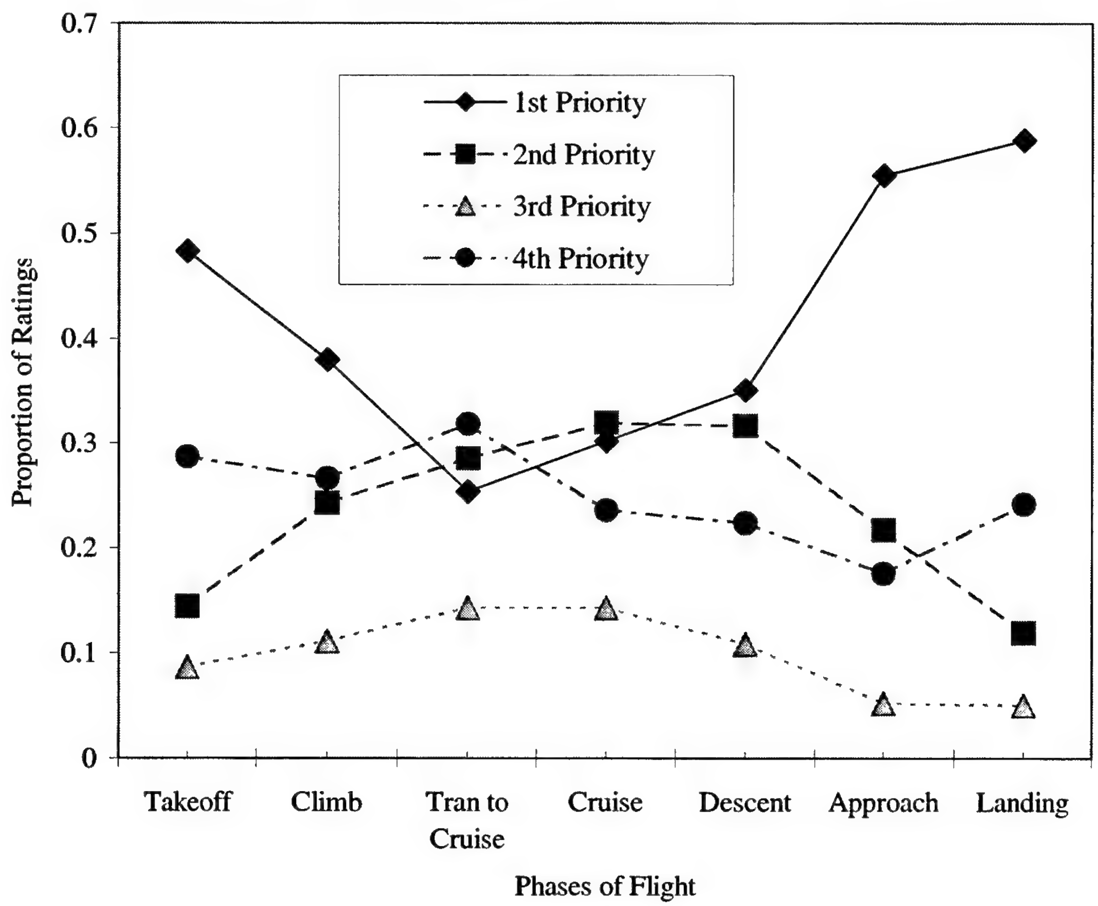

Figure 2. Distribution of ratings across phases of flight.

Table 6. Average priorities of information elements.

Flying			Planning	
Information Element	**Priority**		**Information Element**	**Priority**
RPM (power)	1.44		Fuel quantity	1.35
Airspeed	1.49		General weather	1.39
Engine health	1.58		Time - ETA/ETE	1.57
Traffic	1.66		Wind	1.61
Pitch (attitude)	1.67		Airport configuration	1.78
General weather	1.79		Waypoints	1.85
ATC	1.79		Altitude - MSL	1.87
Aircraft configuration	1.80		Distance	1.93
Altitude - MSL	1.85		Airspace	1.96
Heading	1.89		Course	2.07
Altitude - AGL	1.92		Obstructions	2.07
Wind	1.98		Ground speed	2.09
Traffic / other Comm	1.99		Engine health	2.31
Course	2.13		ATC	2.35
Obstructions	2.13		Fuel selection	2.35
Track	2.13		Heading	2.39
Airspace	2.19		RPM (power)	2.44
Vertical Velocity	2.20		Altitude - AGL	2.44
Bank	2.24		Airspeed	2.50
Fuel selection	2.24		Traffic / other Comm	2.57
Yaw	2.25		Track	2.67
Fuel quantity	2.30		Aircraft configuration	2.67
Airport configuration	2.55		Traffic	2.74
Distance	2.65		Runway remaining	3.22
Ground speed	2.74		Bank	3.43
Waypoints	2.76		Pitch (attitude)	3.46
Runway aim point	2.97		Vertical Velocity	3.48
Time - ETA/ETE	2.98		Yaw	3.50
Runway remaining	2.99		Runway aim point	3.54

Priority and Pilot Experience Level

It is of interest to consider how pilot experience relates to the judgment of priorities. The differences as a function of experience were small, but there are some differences worth considering. Average priority ratings for the various phases of flight and pilot experience level are shown in Figure 3. Values for planning are shown at the right end of the graph for comparison. The more experienced pilots assigned higher overall priorities for the most demanding phases of flight. The 0.12 overall difference in the average priority is significant, $t(6) = 2.62, p = 0.031$.

Information Priorities in Phases of Flight

Next, we turn to an analysis of the details of the priorities in each phase of flight. The goal of this analysis is to define which information elements have high priority in particular phases. Such data would be useful in designing dynamic information displays that provide the most relevant information at the proper time. Figure 4 through Figure 12 show the information priorities associated with each phase of flight. The figures are organized so that the information elements are sorted for each phase of flight using the average priority of the more-experienced pilots (Exp). The average priority of the novice pilots (Nov) is also shown for comparison. Points of substantial differences between the two groups of pilots may identify areas that could usefully be addressed in training. Table 7 lists the significant differences using $p = 0.05$. All differences with chance probability less than or equal to 0.05 are shown along with the probability of a difference at least this large by chance according to a two-tailed t-test with 25 df. Because these differences are selected from a large set of tests (9 phases of flight x 29 information elements = 261 tests), we would expect to find 13 (5% of 261) such significant differences by chance alone. Thus, the 16 significant differences found should be viewed with caution. The lower p values shown on the table show which differences are most likely to be reliable, and the repeated occurrence of significant differences associated with the same information element leads to greater confidence in those effects.

As the overall means suggested earlier, there is a clear tendency for more experienced pilots to assign higher priorities. Most of the differences in 7 have the more experienced pilots assigning the higher priority. Novice pilots may have less capacity available to deal with all of the important information, so some of it takes lower priority. It is important to distinguish between what should be high priority and what can be high priority given the pilot's ability. Interestingly the novice pilots appear to assign priority ratings in

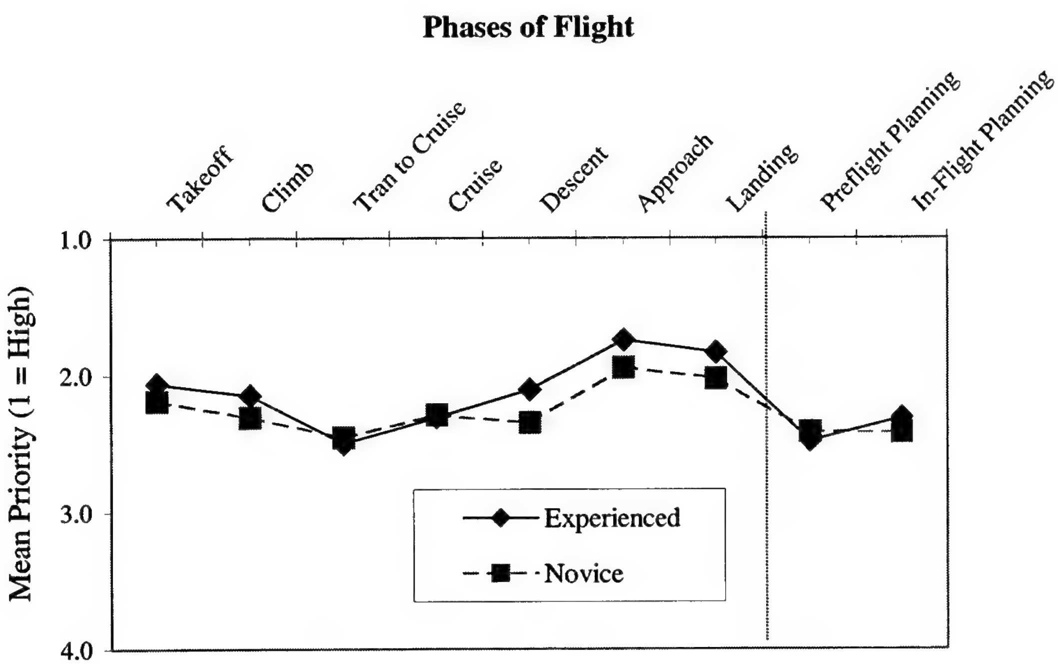

Figure 3. Priorities, phase of flight, and experience.

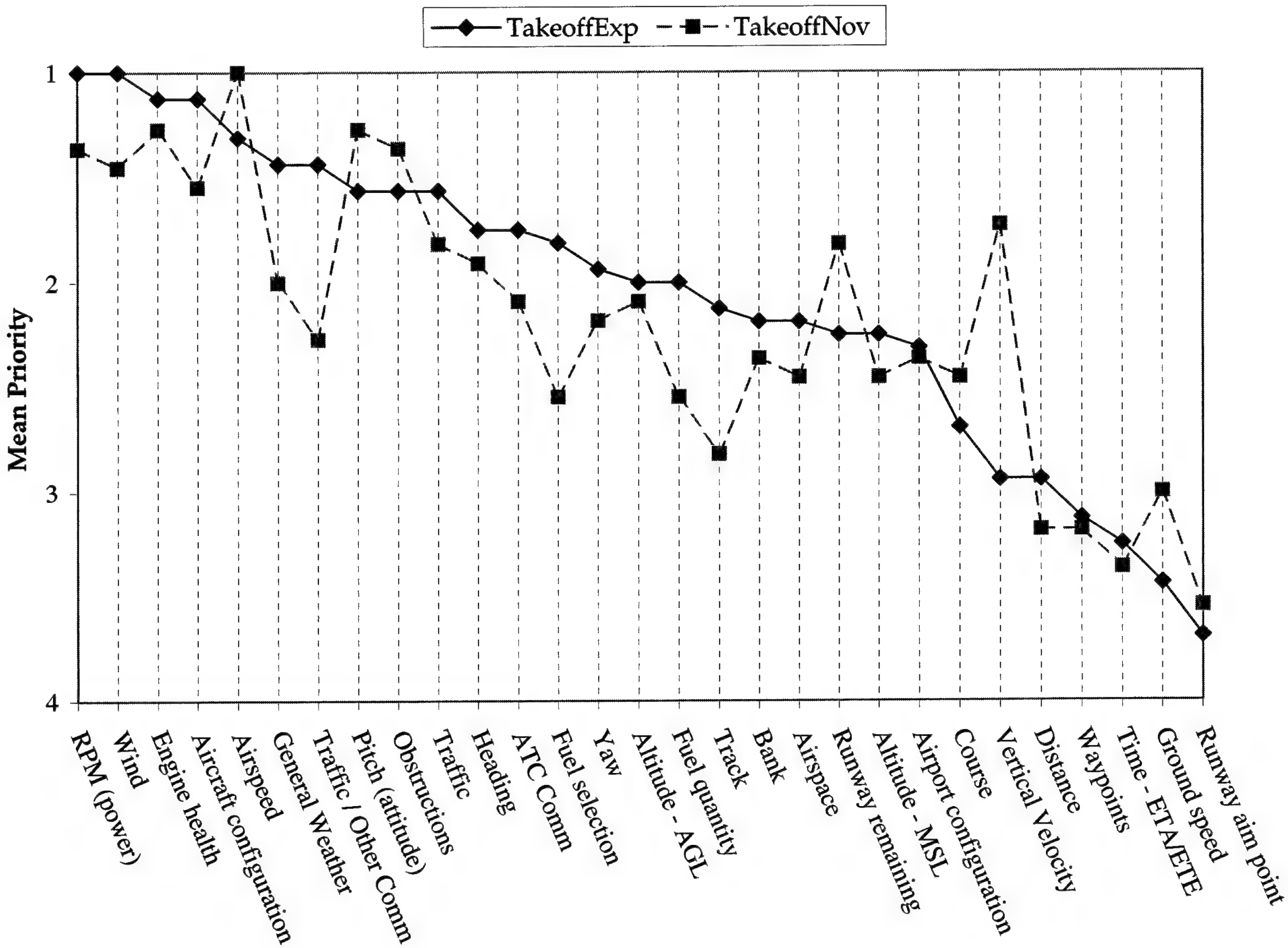

Figure 4. Takeoff priorities.

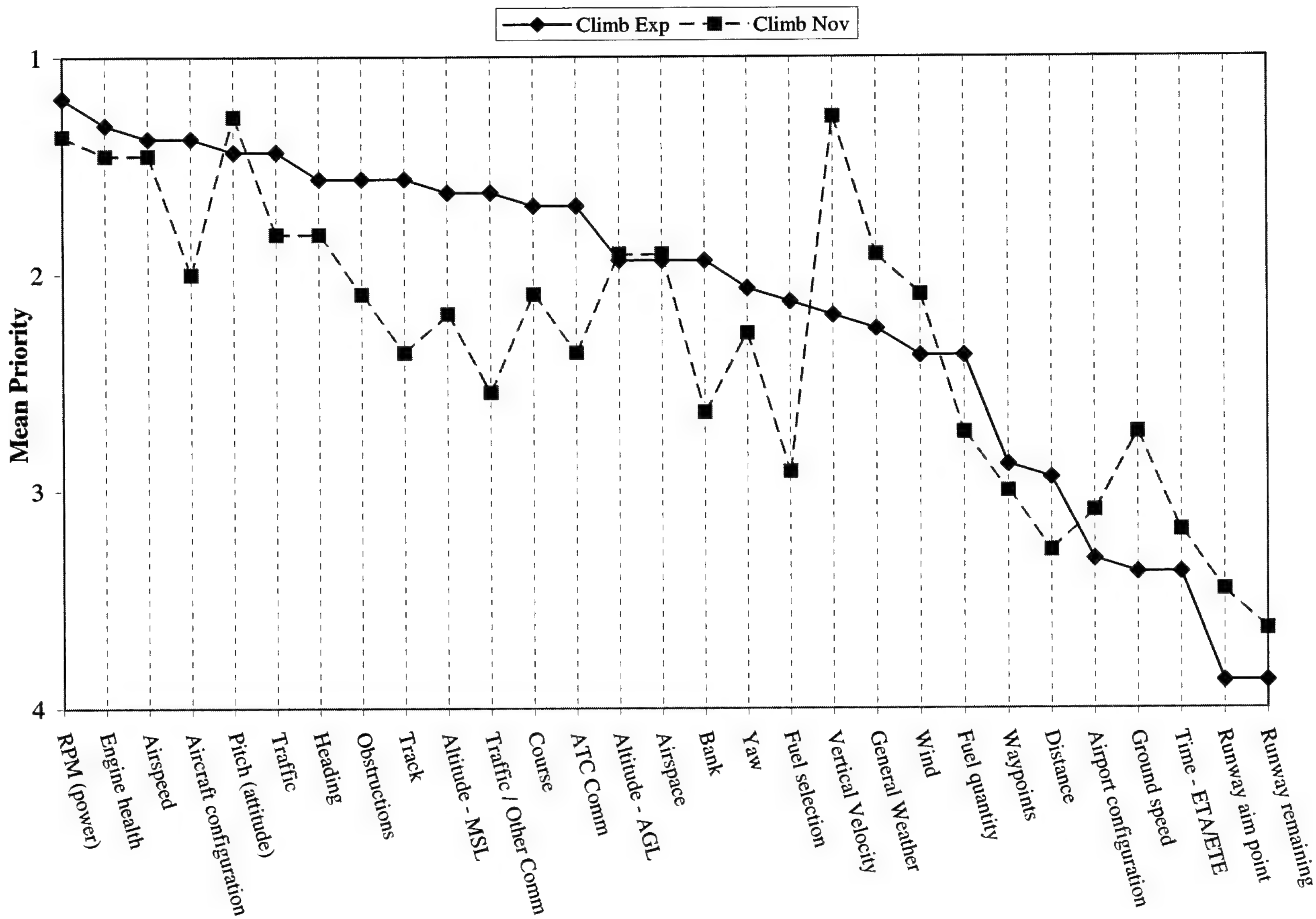

Figure 5. Climb priorities.

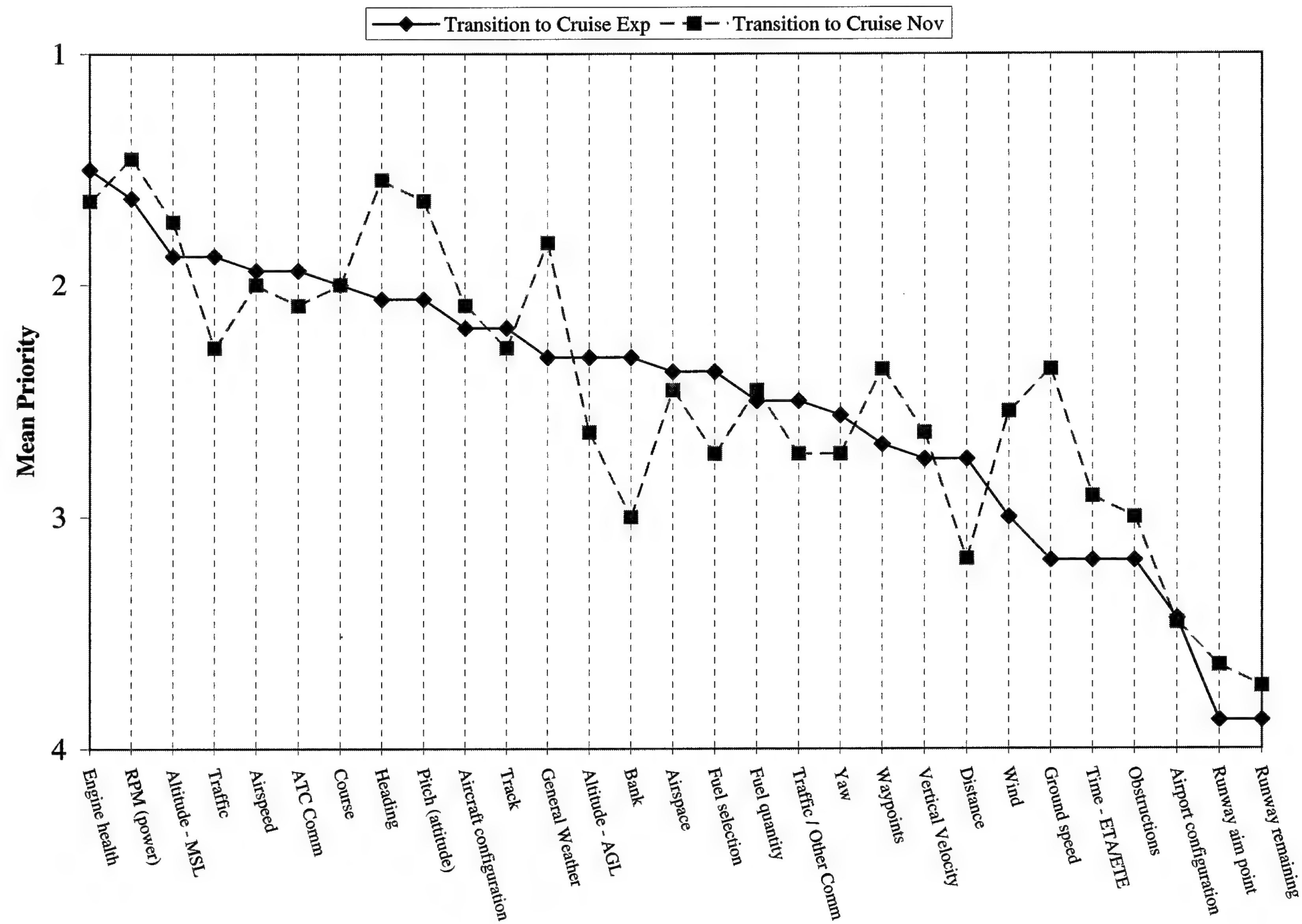

Figure 6. Transition to cruise priorities.

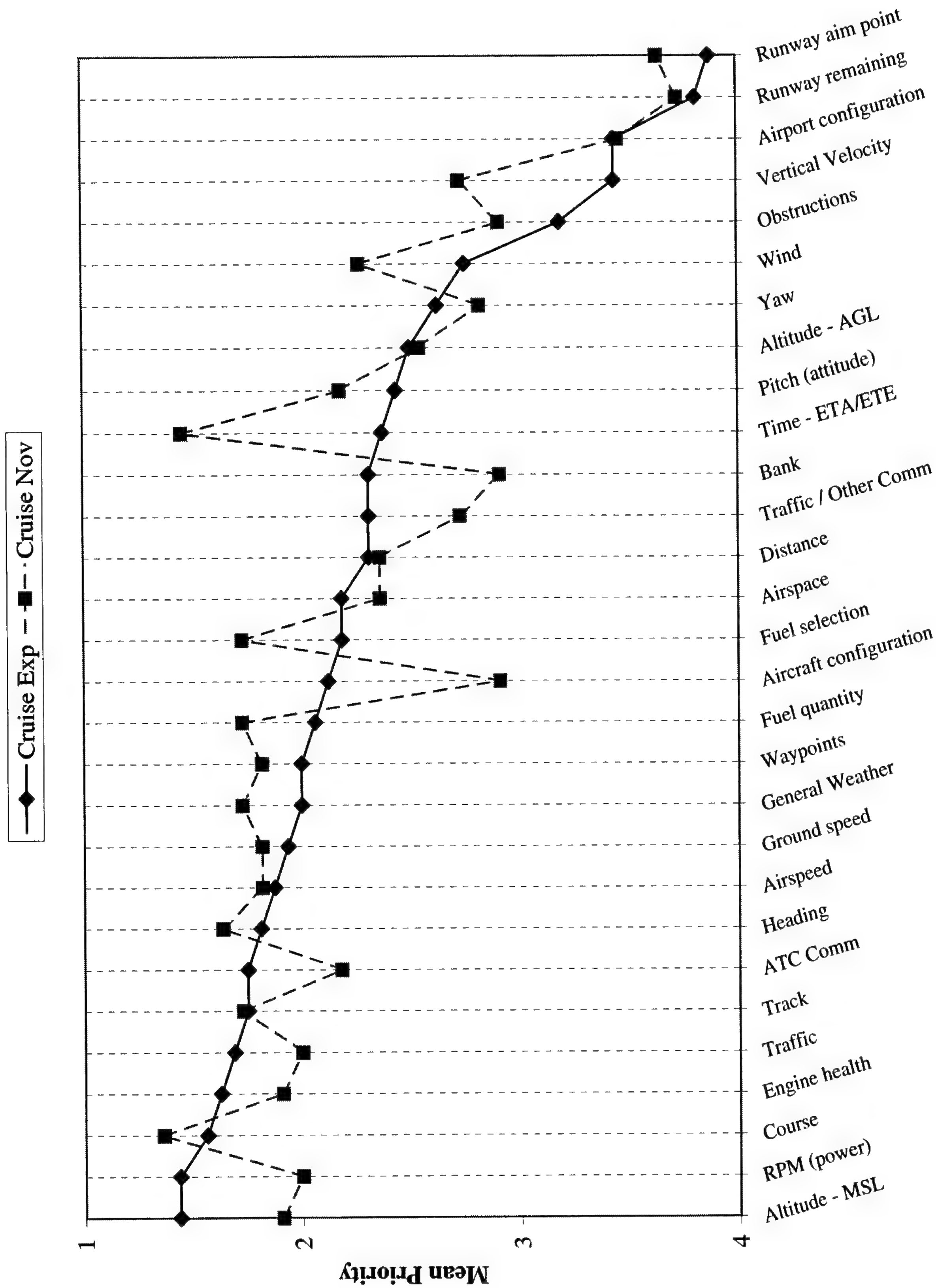

Figure 7. Cruise priorities.

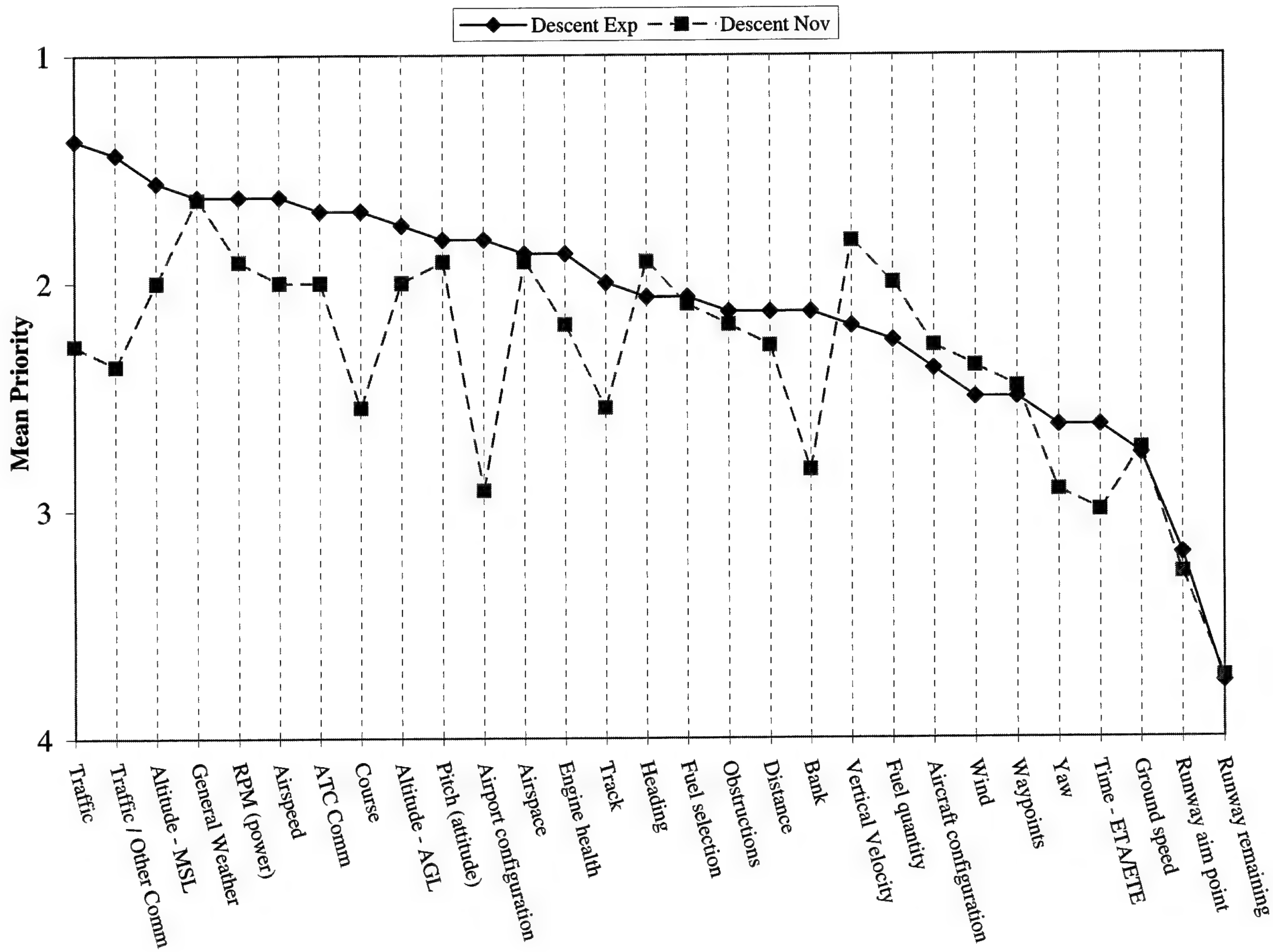

Figure 8. Descent priorities.

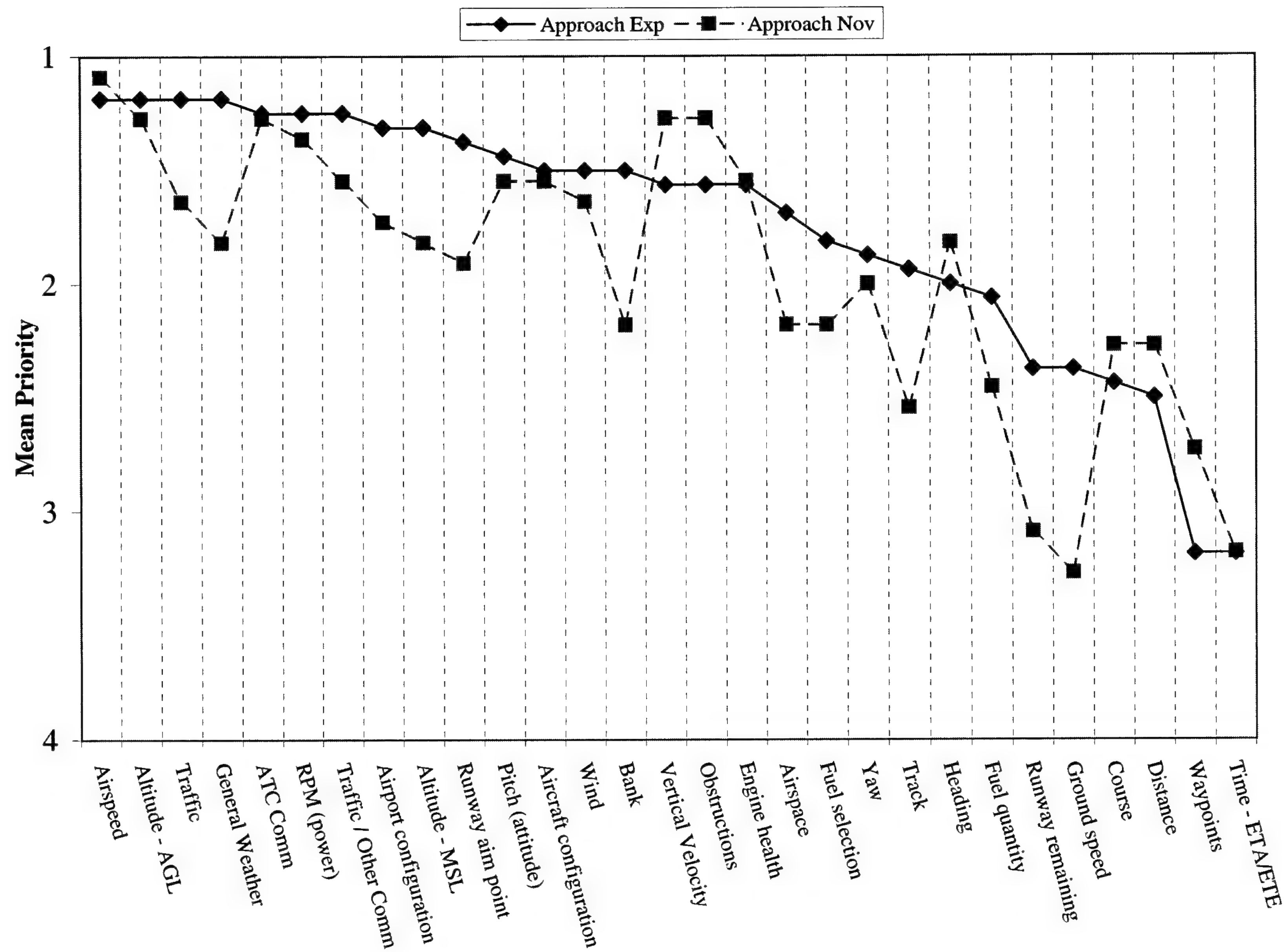

Figure 9. Approach priorities.

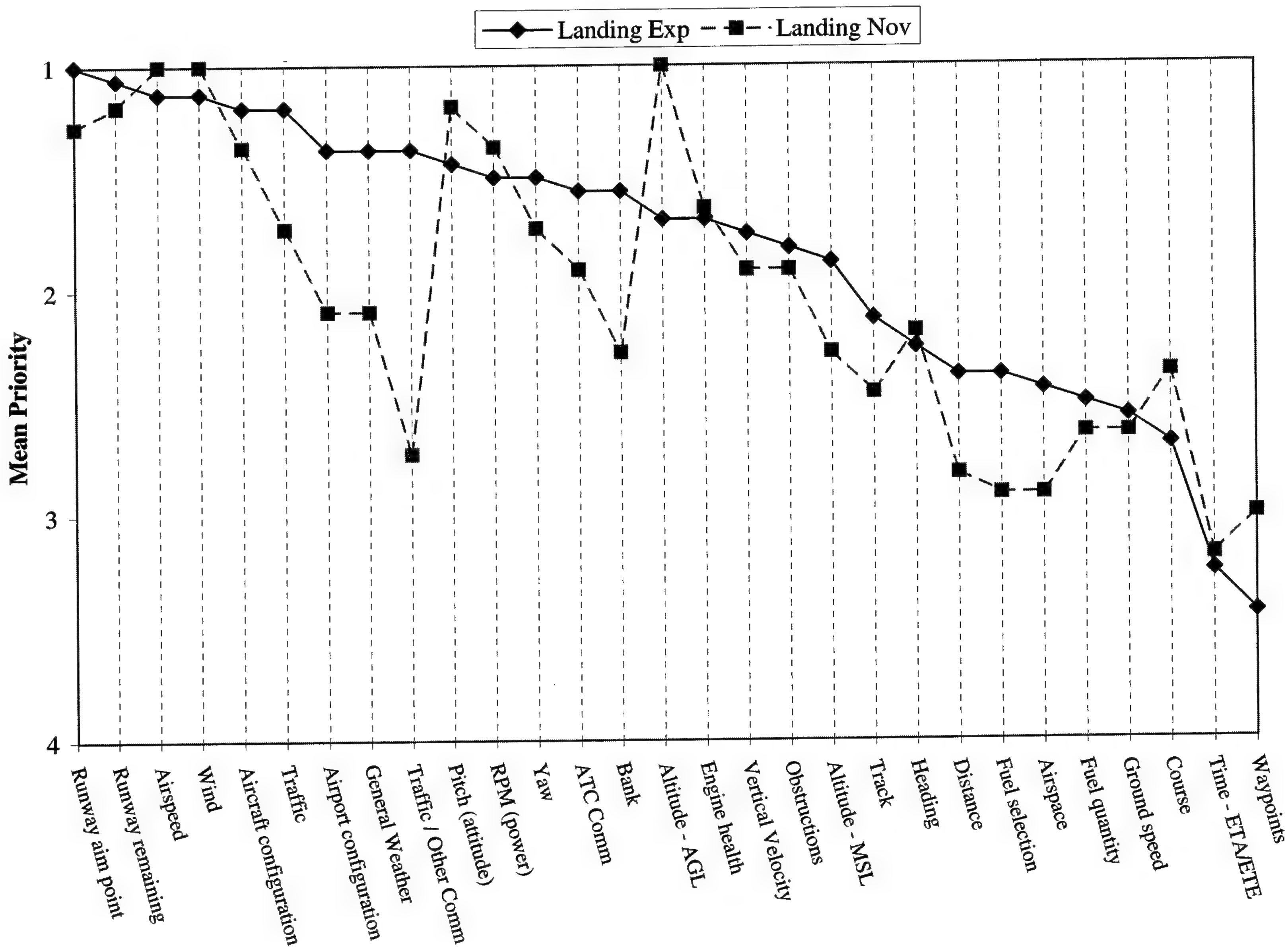

Figure 10. Landing priorities.

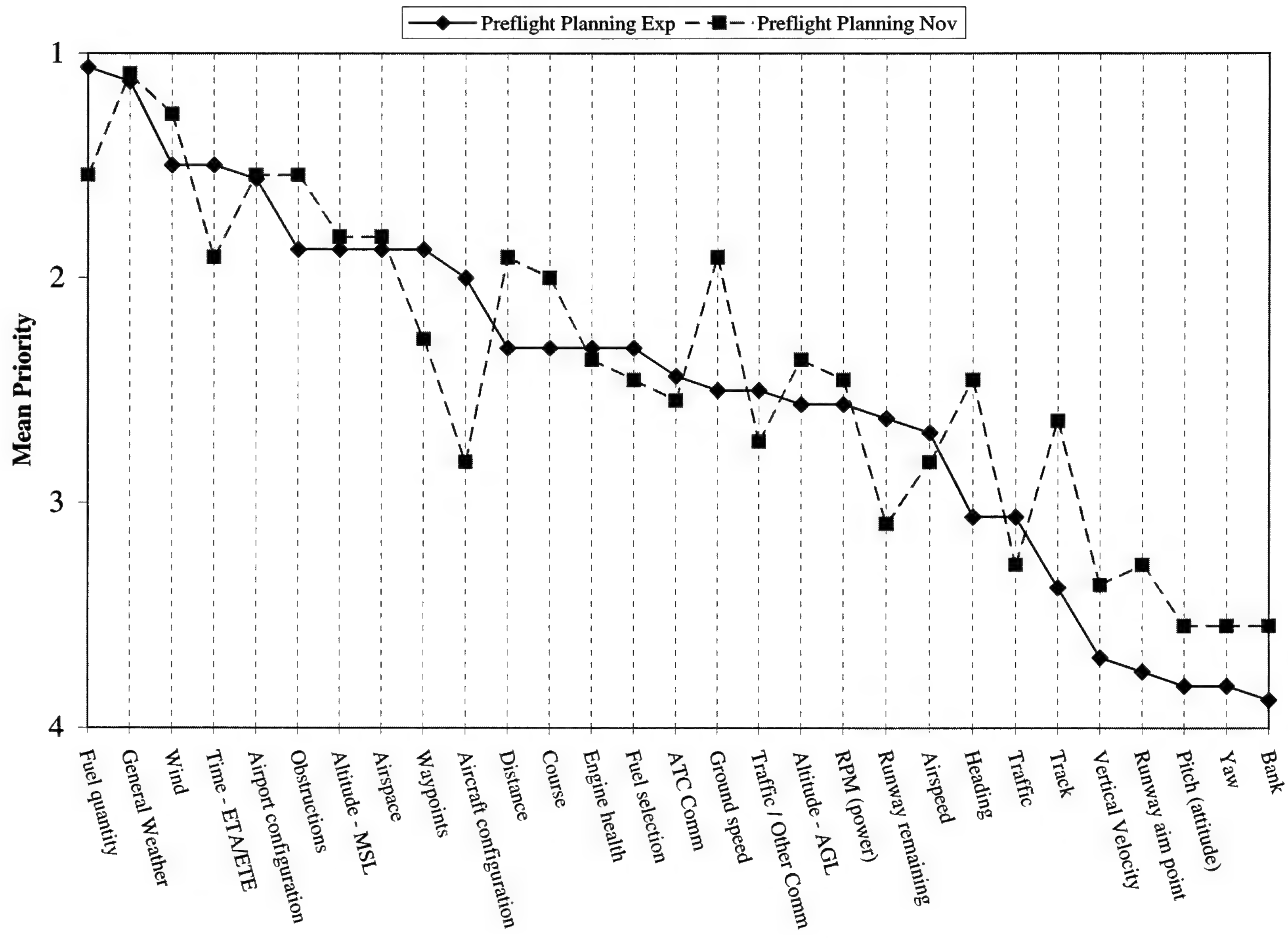

Figure 11. Preflight planning priorities.

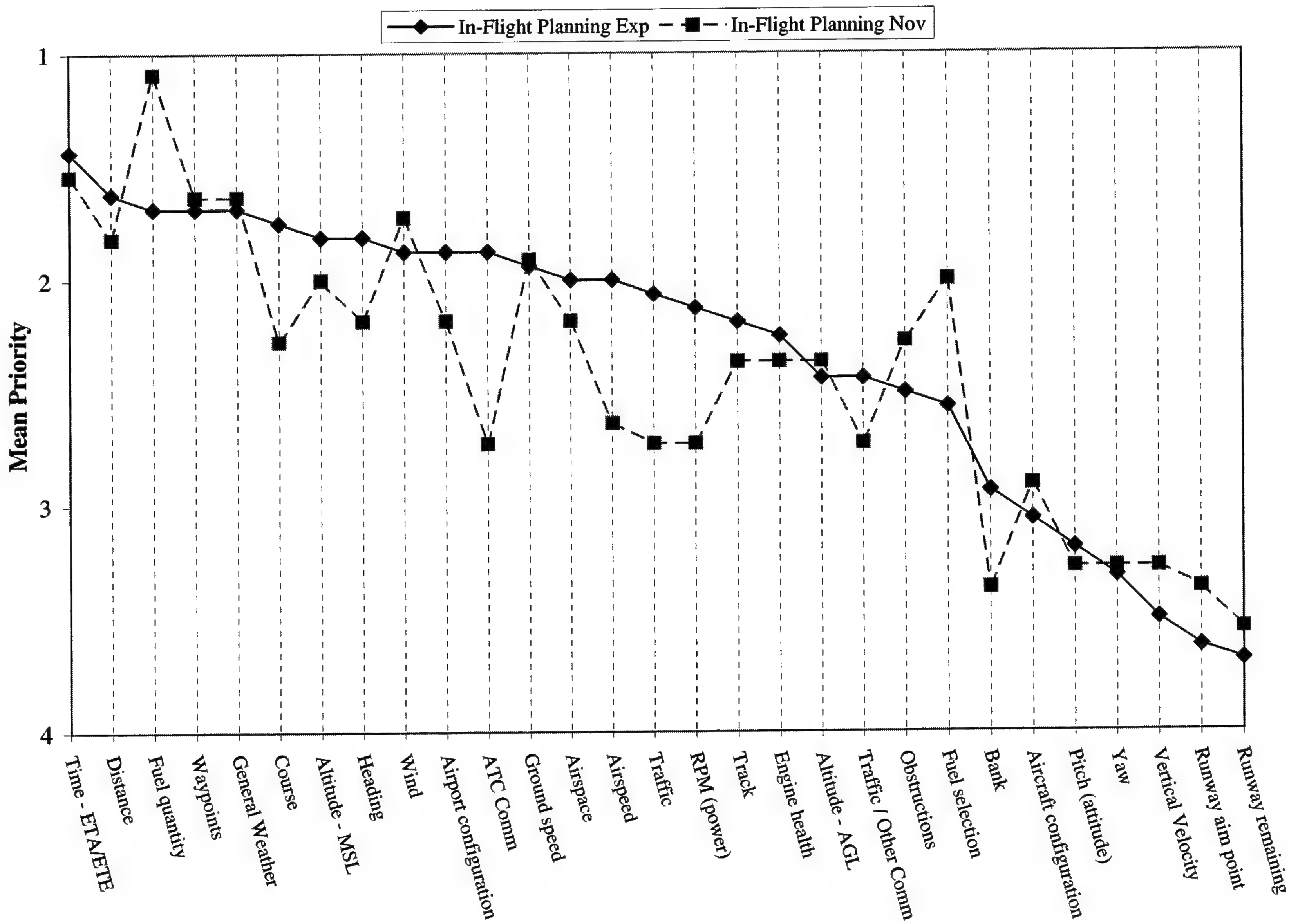

Figure 12. In-flight planning priorities.

Table 7. Major novice-experienced priority differences.

Phase	Information Element	Higher Priority by:	*p*
Takeoff	Vertical Velocity	Nov	.015
Climb	Track	Exp	.025
	Traffic/Other Comm	Exp	.043
	Vertical Velocity	Nov	.016
Transition to Cruise	Ground Speed	Nov	.046
Cruise	RPM (power)	Exp	.032
	Time - ETA/ETE	Nov	.011
	Vertical Velocity	Nov	.043
Descent	Traffic	Exp	.022
	Traffic/Other Comm	Exp	.005
	Course	Exp	.028
	Airport Configuration	Exp	.013
Approach	General Weather	Exp	.056
Landing	Runway Aim Point	Exp	.027
	Traffic/Other Comm	Exp	.005
In-Flight Planning	ATC Comm	Exp	.043

Table 8. Highest priority information by phase of flight.

	Flying								Planning		
Information Element	**TO**	**Clmb**	**TTC**	**Cruse**	**Desc**	**App**	**Land**	**Num**	**PP***	**IFP+**	**Num**
Aircraft configuration	X	X				X	X	4	X		1
Engine health	X	X	X	X	X	X	X	7			0
Fuel quantity	X							1	X	X	2
Fuel selection	X					X		2			0
RPM (power)	X	X	X	X	X	X	X	7			0
Altitude - AGL	X	X	X	X	X	X	X	7			0
Altitude - MSL		X			X	X	X	4	X	X	2
Distance								0		X	1
Bank		X				X	X	3			0
Pitch (attitude)	X	X			X	X	X	5			0
Yaw	X					X	X	3			0
Course		X	X	X	X			4		X	1
Heading	X	X		X		X		4		X	1
Track		X		X	X	X		4			0
Waypoints				X				1	X	X	2
Airspeed	X	X	X	X	X	X	X	7		X	1
Ground speed				X				1		X	1
Vertical velocity						X	X	2			0
Time - ETA/ETE								0	X	X	2
Airport configuration					X	X	X	3	X	X	2
Runway aim point						X	X	2			0
Runway remaining							X	1			0
ATC comm	X	X	X	X	X	X	X	7		X	1
Traffic / other comm	X	X			X	X	X	5			0
Obstructions	X	X				X	X	4	X		1
Traffic	X	X	X	X	X	X	X	7			0
Airspace		X			X	X		3	X	X	2
General weather	X			X	X	X	X	5	X	X	2
Wind	X					X	X	3	X	X	2

* Preflight planning
\+ In-flight planning

line with their capacity rather than with what might be the ideal priority. Some information elements show experience differences in more than one phase of flight. Traffic/Other Communication consistently receives higher priority ratings from the experienced pilots. In contrast, novices assign higher priority ratings to Vertical Velocity in Takeoff, Climb, and Cruise. Perhaps experienced flyers focus on factors such as pitch and power and let the vertical velocity take care of itself, while novice flyers focus directly on vertical velocity. Instructor pilots may find it useful to consider these priority differences as they think about what topics to discuss with their students.

Table 8 gives another view of the priorities in the phases of flight. The information elements with a mean priority rating of 2 or better are shown for each phase of flight. The items that are critical in all of the flying phases are often available in the central instrument cluster, but not all of the critical information elements are found there. Some items have high priority in planning, but not in flying. It may be worth considering how to deal with planning versus flying information as displays are designed.

Information Priorities and Workload

Considerable attention has been devoted to characterizing and assessing workload both under normal operating conditions and under various unusual situations (Corwin, 1992; Gopher & Donchin, 1986; Moray, Johanssen, Pew, Rasmussen, Sanders, & Wickens, 1979). Pilots generally report that workload is greater in some phases of flight than in others. Takeoff, approach, and landing are usually identified as the phases involving the highest workload under normal operating conditions. The priority ratings we collected in the present study offer an additional way to measure workload. We propose that the average priority rating for data within a phase of flight will reflect workload, namely, the higher the average priority rating, the higher the workload. Another measure from our study is also worth examining for its relation to workload: the proportion of the highest priority ratings in the set of ratings for a phase of flight. Presumably, the higher the proportion of highest-priority (i.e., priority 1) information elements, the higher the workload.

To test these ideas, we examined previous studies of workload in the literature. One study, Corwin (1992), was particularly appropriate for our purposes because that study assessed workload both in-flight and post-flight for three simulator flights. One flight was a 30-minute flight between two airports. A second 30-minute flight was similar, with the addition of communications. The third 1.5-hour flight involved malfunctions with two diversions, an engine failure, and a hydraulic system failure. Using the Subjective Workload Assessment Technique (SWAT), workload was assessed both in-flight and post-flight for each of several phases of flight (takeoff, climb, top of climb, cruise, top of descent, approach, and landing). These phases match up very well with the flying phases we defined for our priority ratings (takeoff, climb, transition to cruise, cruise, descent, approach, and landing). The values of the various measures are shown in Table 9, along with the correlations between these measures. Interestingly, the measures derived from the priority ratings of the present study correlate about as well with the measures from the Corwin study as those measures correlate with each other. SWAT measures were more highly correlated with the percentages of priority ratings falling in the top priority category than they were with the mean priority ratings. This result suggests that workload may derive primarily from high-priority data requirements, rather than from the total potential data requirements.

While this is a rather appealing notion, it should be kept in mind that this is based upon correlational data, and thus no causality can be directly inferred from these observations. A slightly stronger case can be made, however, if one looks at additional sources of data, i.e., the data requirements per flight phase and the distribution of accidents by flight phase. Accidents are distributed disproportionately across phases of flight such that the frequency of incidents and accidents on take-off and approach/landing is far greater, by a significant amount, than the times of exposure to these phases of flight. Although several factors are thought to influence this distribution, it is widely accepted that workload is higher during take-off or approach than it is during level cruise. Examinations of information requirements by phase of flight indicate that changes in aircraft configuration, increases in communications requirements, increases in traffic in the terminal area, and requirements for maintaining separation all contribute to an elevated workload during the approach and landing. It is documented that more data are needed per unit time during an approach and landing than are accessed during a cruise flight segment. If we can assume that

Table 9. Workload measures and correlations.

Phase	A Exper. Mean Priority Rating	B Exper. Percent Top Priority	C Corwin Basic In-Flight	D Corwin Basic Post-Flight	E Corwin Comm In-Flight	F Corwin Comm Post-Flight	G Corwin Malfn In-Flight	H Corwin Malfn Post-Flight
Takeoff	2.06	53.7%	24.9	25.6	24.5	27.8	20.0	16.3
Climb	2.15	41.6%	11.1	14.4	19.6	15.6	14.7	12.7
Trans'n to Cruise	2.50	24.4%	9.1	3.9	11.7	10.2	1.4	2.9
Cruise	2.30	28.9%	2.9	1.3	8.6	11.4	14.1	21.3
Descent	2.10	36.4%	16.8	16.9	15.2	16.8	13.1	18.2
Approach	1.74	59.1%	15.9	14.9	19.3	17.1	32.2	33.7
Landing	1.83	62.9%	30.4	26.5	29.4	29.0	46.4	59.9

Correlations	A	B	C	D	E	F	G	H
A		-0.94	-0.67	-0.71	-0.72	-0.66	-0.89	-0.77
B	-0.94		0.82	0.84	0.90	0.83	0.91	0.77
C	-0.67	0.82		0.96	0.93	0.95	0.73	0.65
D	-0.71	0.84	0.96		0.94	0.95	0.68	0.56
E	-0.72	0.90	0.93	0.94		0.93	0.78	0.66
F	-0.66	0.83	0.95	0.95	0.93		0.74	0.64
G	-0.89	0.91	0.73	0.68	0.78	0.74		0.96
H	-0.77	0.77	0.65	0.56	0.66	0.64	0.96	

higher-priority data are "required" whereas lower-priority data are optional in some cases, then we can forge a link between the percentage of information elements rated as high-priority and the expected workload resulting from the increased information-processing requirements.

Project 3: The Mental Organization of Information Accessed in Flight

In this project, we used network scaling-methods to analyze how pilots conceptually organize the information used in flight. First, we present some background on network scaling.

Network Analyses of Relatedness Data

The techniques used in the present analysis are generally known as Pathfinder Network Scaling (see Schvaneveldt, 1990). The method uses individuals' judgments as a source from which to extract underlying network structures. This method has been used to capture expert-novice differences in conceptual structure (USAF pilots – Schvaneveldt, et al., 1985; also see Cooke & Schvaneveldt, 1988 and Rowe, Cooke, Hall & Halgren, 1996), to assess student knowledge (Goldsmith, Johnson, & Acton, 1991), and to analyze and design user-system interfaces (McDonald & Schvaneveldt, 1988).

Graph Theory and Relations Among Information Elements

The abstract model underlying the proposed model of relationships among information elements is graph and network structures. In mathematical graph theory, a graph is an abstraction consisting of a set of nodes and a set of pairs of the nodes (Harary, 1969). Each such pair of nodes is called a link. The links can be directed or undirected. The nodes represent some entity (concept, document, individual, process, etc.) and the links represent relationships between nodes. A network is a graph with weights (or costs) associated with the links. We often expand these basic definitions to include distinguishing different types of nodes and different types of links. The present application can benefit from the ability to systematically distinguish different node and link types. For example, node types can be used to represent collections of related nodes, which, for some purposes, may be treated as a single category (e.g., the various parameters relating to the status of engines).

METHOD

Pathfinder scaling requires judgments of relatedness for the pairs of elements to be scaled. Pathfinder produces a network showing the connections between the various elements. The network structures also reveal clusters of elements that are interrelated. Because the relatedness judgments require pilots to evaluate all pairs of the elements, the number of elements must be limited. We selected the information elements shown in Table 10 for study in this project. To limit the number of items, we excluded information more related to airports, while retaining the items related to flying the aircraft and to communications.

Table 10. The 22 information elements used for relatedness ratings.

Aircraft Configuration	Airspeed
Engine Health	Ground Speed
Fuel Status	Vertical Velocity
RPM (power)	Time (ETA/ETE)
Altitude	ATC Comm
Distance to Waypoint	Traffic Comm
Bank	Obstructions
Pitch	Traffic
Yaw	Airspace
Course	General Weather
Track	Wind

Participants

Thirty-four certified pilots of varying age and experience were used to obtain the relatedness rating data. A number of subjects overlap from the priority-rating task to the relatedness-rating task. The participants were obtained from different areas around the United States. To examine the impact of experience on judgments of relatedness, we separated the pilots into two groups based on their total flying time. The hours of the 15 less experienced pilots ranged from 100 to 950 with a mean of 372 and a standard deviation of 323. The 19 more experienced pilots had a range of flying time from 1,000 to 20,400 hours with a mean of 5,320 and a standard deviation of 5,143. Thirteen percent of the less-experienced pilots held the Instrument Rating while 74% of the more-experienced pilots were instrument rated.

Materials

The relatedness-rating task was conducted using two Hewlett-Packard OmniBook 600c laptop computers. A MS/DOS program presented instructions and all of the 231 pairs of the 22 information elements for relatedness ratings.

Design and Procedure

Collection of the relatedness data occurred over an eight-month period. The participants completed a demographic questionnaire (see Appendix 1). After the demographic form was completed, the participants were directed to the computer for the relatedness ratings. After reviewing the 22 information elements to be rated, the pilots rated the relatedness for each of the pairs of elements. The 231 pairs were presented in a different random order for each participant. At the conclusion of the rating task, the project was discussed with the pilots, and they were encouraged to provide feedback about the rating task and the objectives of the study.

RESULTS AND DISCUSSION

The Pathfinder network derived from the average of all of the relatedness rating data is shown in Figure 13. The figure generally reveals which items of information are most closely related to which other items by virtue of the links in the figure. Linked nodes indicate a close relationship between the items linked. Judged by the number of links connected to the nodes, Course, Altitude, Airspeed, and Power are the central nodes in the figure. Arguably, these items are also central to the flight task. Airspeed is required for lift. Power is essential to produce Airspeed. Course and Altitude are essential parts of navigation. The other information elements all tie to these core elements to give a more complete picture of the information required in flight. Thus, the picture of the organization of the information revealed by the network analysis generally corresponds with intuitive impressions, as it is intended to do.

Table 11 gives more detail about the close connections among information elements. The table shows the most closely related pairs of items based on judged relatedness (rel) and/or the frequency with which the pairs are linked in the networks of 34 individual pilots (net).

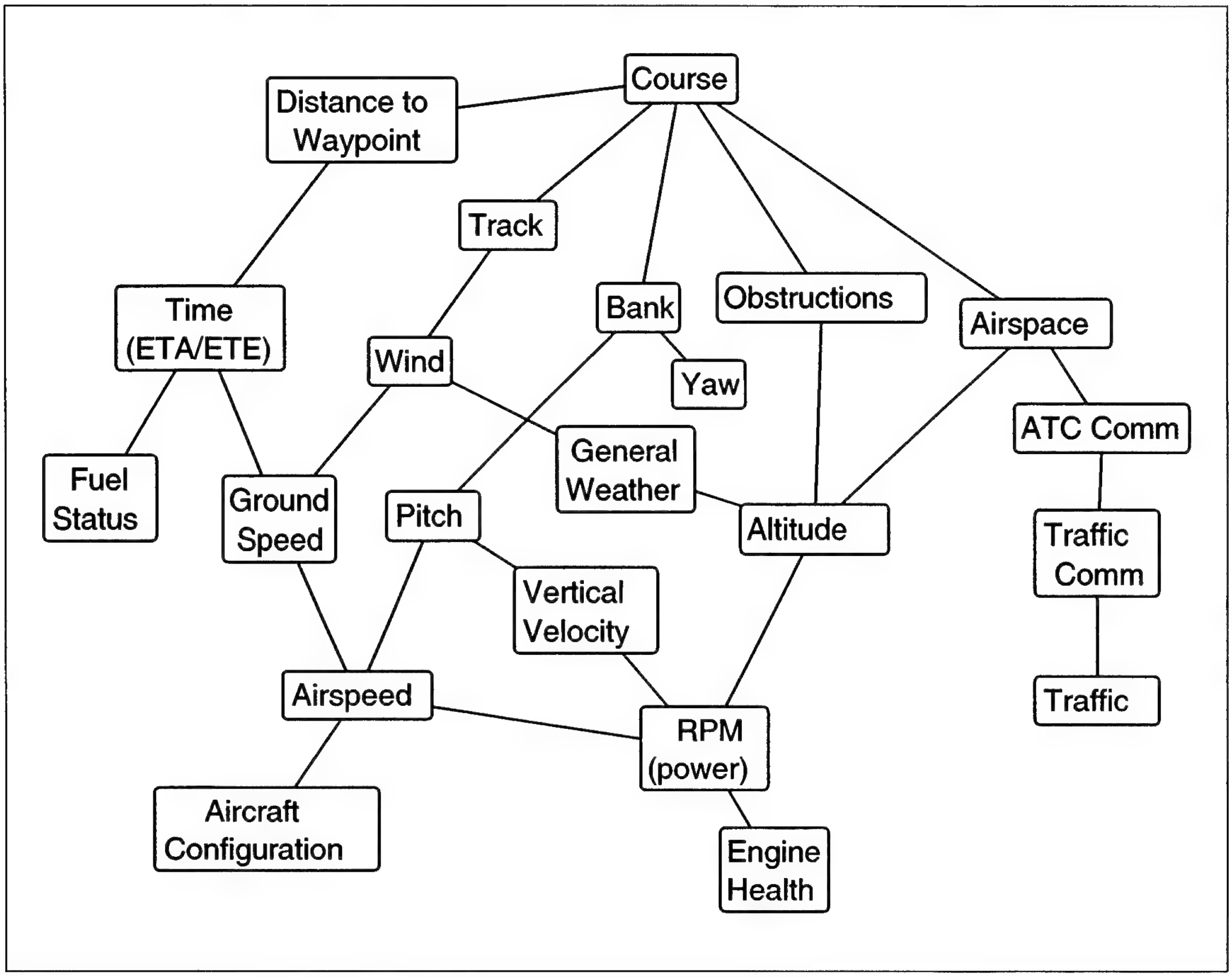

Figure 13. The pathfinder network for average data (q=2, r=8).

Table 11. Most highly connected pairs of information elements.

Net	Rel	Pair		Net	Rel	Pair	
32	8.8	Time (ETA/ETE)	Ground Speed	16	6.5	Wind	Distance to Waypoint
31	8.6	Wind	Ground Speed	11	7.0	General Weather	Altitude
30	8.6	Time (ETA/ETE)	Distance to Waypoint	13	7.0	Track	Distance to Waypoint
30	8.4	Obstructions	Altitude	11	7.0	Ground Speed	Track
29	8.4	RPM (power)	Engine Health	15	7.0	Vertical Velocity	Aircraft Configuration
28	8.4	Track	Course	11	6.9	Wind	Altitude
27	8.3	Traffic	Traffic Comm	13	6.9	Ground Speed	Course
27	8.4	Airspace	ATC Comm	13	6.9	ATC Comm	Altitude
27	8.1	Wind	Track	13	6.8	Ground Speed	Aircraft Configuration
26	8.2	Traffic Comm	ATC Comm	9	6.8	General Weather	Course
25	8.3	Airspeed	RPM (power)	15	6.3	Pitch	Bank
25	8.3	Time (ETA/ETE)	Airspeed	15	5.5	Yaw	Bank
25	8.3	Wind	Time (ETA/ETE)	14	6.8	Obstructions	Vertical Velocity
25	8.2	Wind	General Weather	13	6.7	Traffic	Altitude
24	7.9	Airspeed	Pitch	10	6.7	Course	Fuel Status
24	8.2	Vertical Velocity	Pitch	7	6.7	Airspeed	Altitude
24	8.0	Time (ETA/ETE)	Fuel Status	14	6.6	Pitch	Aircraft Configuration
24	7.8	Airspace	Traffic	13	6.6	Airspeed	Engine Health
23	7.9	Airspeed	Aircraft Configuration	11	6.6	Airspeed	Fuel Status
23	8.4	Ground Speed	Airspeed	12	6.6	Pitch	RPM (power)
22	7.8	Airspace	Altitude	7	6.6	Traffic	Course
21	7.5	Distance to Waypoint	Fuel Status	10	6.6	General Weather	Time (ETA/ETE)
21	7.6	Time (ETA/ETE)	Track	9	6.5	General Weather	Airspace
20	8.0	Airspace	Traffic Comm	13	6.4	Time (ETA/ETE)	Engine Health
20	7.7	Traffic	ATC Comm	12	6.3	Fuel Status	Engine Health
20	7.7	Wind	Course	10	6.3	Ground Speed	Altitude
20	6.7	Wind	Airspeed	11	6.3	Ground Speed	Pitch
19	7.9	Wind	Fuel Status	12	6.3	ATC Comm	Course
19	7.9	Ground Speed	RPM (power)	13	6.3	RPM (power)	Aircraft Configuration
19	7.8	Obstructions	Course	9	6.3	Course	Altitude
17	7.7	Course	Distance to Waypoint	10	6.3	Obstructions	Pitch
19	7.7	Altitude	RPM (power)	8	6.2	Traffic Comm	Altitude
19	7.6	Ground Speed	Distance to Waypoint	10	6.2	Airspace	Obstructions
18	7.6	Airspeed	Distance to Waypoint	6	6.2	General Weather	Ground Speed
18	7.6	Vertical Velocity	RPM (power)	12	6.1	Altitude	Engine Health
17	7.4	Vertical Velocity	Altitude	10	6.1	Airspeed	Bank
17	7.3	Time (ETA/ETE)	RPM (power)	10	6.1	Airspace	Airspeed
17	7.3	Obstructions	Track	6	6.1	Altitude	Aircraft Configuration
17	7.3	Pitch	Altitude	10	6.1	Distance to Waypoint	RPM (power)
16	7.2	Time (ETA/ETE)	Course	8	6.1	General Weather	Obstructions
14	7.2	Airspace	Course	9	6.0	Airspace	Track
12	7.2	RPM (power)	Fuel Status	9	5.9	Ground Speed	Fuel Status
12	7.2	Vertical Velocity	Airspeed	11	5.9	ATC Comm	Time (ETA/ETE)
13	7.2	General Weather	Fuel Status	9	5.9	Airspace	Ground Speed

Clusters of Information Elements

The results of a hierarchical cluster analysis are shown in Figure 14. Bold lines surrounding the information elements show clusters. The cluster analysis reveals larger groupings of the information elements, which may be useful in suggesting organizations of information displays. The clusters generally identify meaningful hierarchical groupings of the information elements.

The information clusters suggest how pilots reach decisions by considering multiple factors. For example, the clustering of Distance to Waypoint and Fuel Status illustrates the decision-making about the likelihood of reaching a waypoint. This cluster is closely connected to the cluster including Time and Ground Speed and Wind, reflecting the relevance of all of these factors in decision-making in flight. Presenting such information in an arrangement and a format that facilitates decision-making should be of considerable value to pilots.

Experience and Networks

We examined the differences between the network derived from the ratings of novice pilots and that derived from the ratings of experienced pilots. The networks were generated with r = ¥ and q = 2 which yields networks with the maximum number of links given ordinal data (Schvaneveldt, Durso, & Dearholt, 1989). The experienced-pilots' network had 28 links while the novices' network had 29. In general, the similarities in the two networks were more striking than the differences. The two networks had 21 links in common. The differences between the networks are shown in Figure 15. Many were simply differences in the linking among three items. Such differences in triples of items are not particularly significant because the three items are joined in both networks albeit with different links. It is possible, however, that the different linking points to subtle differences in the way novices and experienced pilots think about the information involved. In Figure 15, the triangles

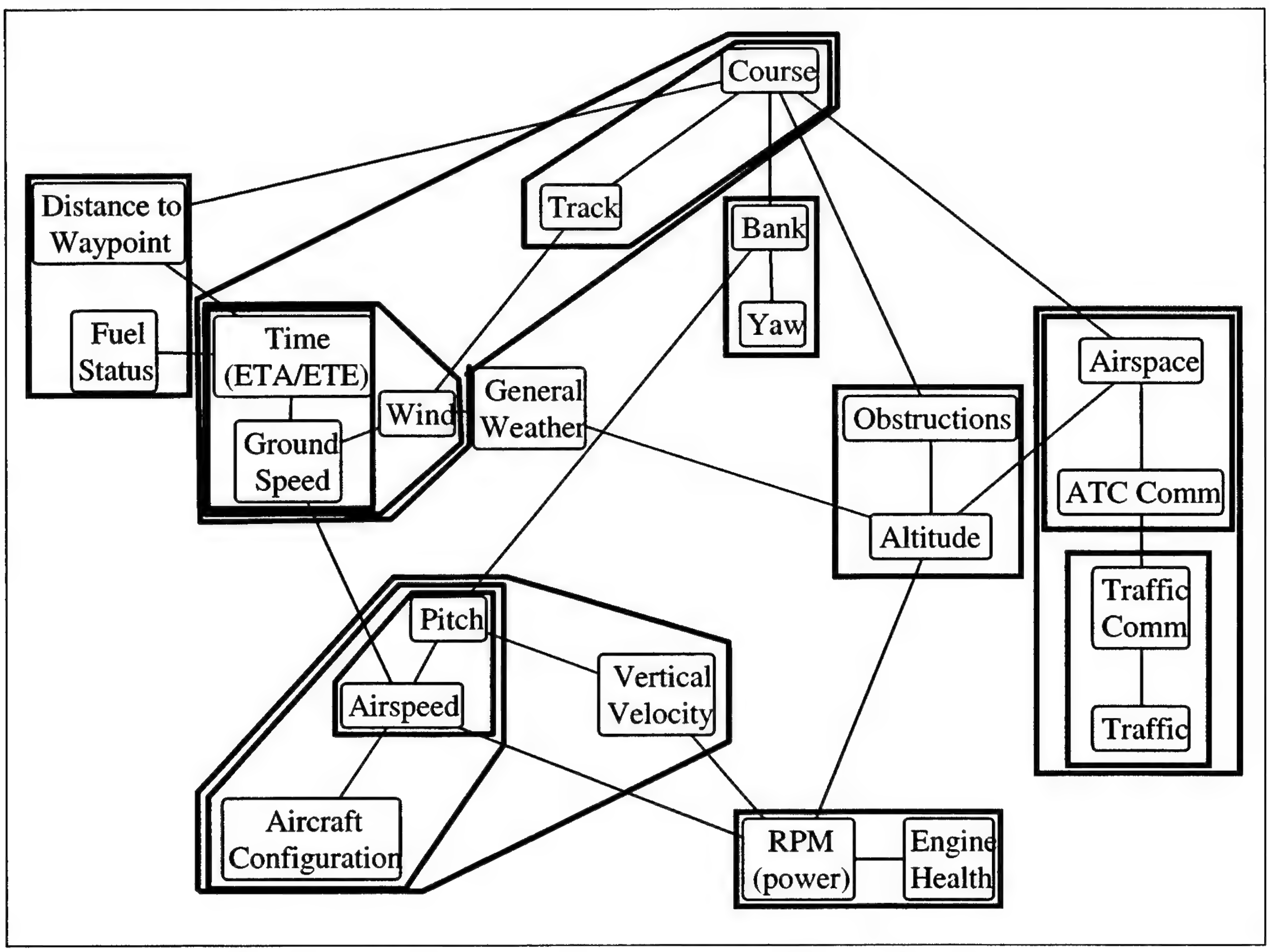

Figure 14. Hierarchical clusters in the pathfinder network.

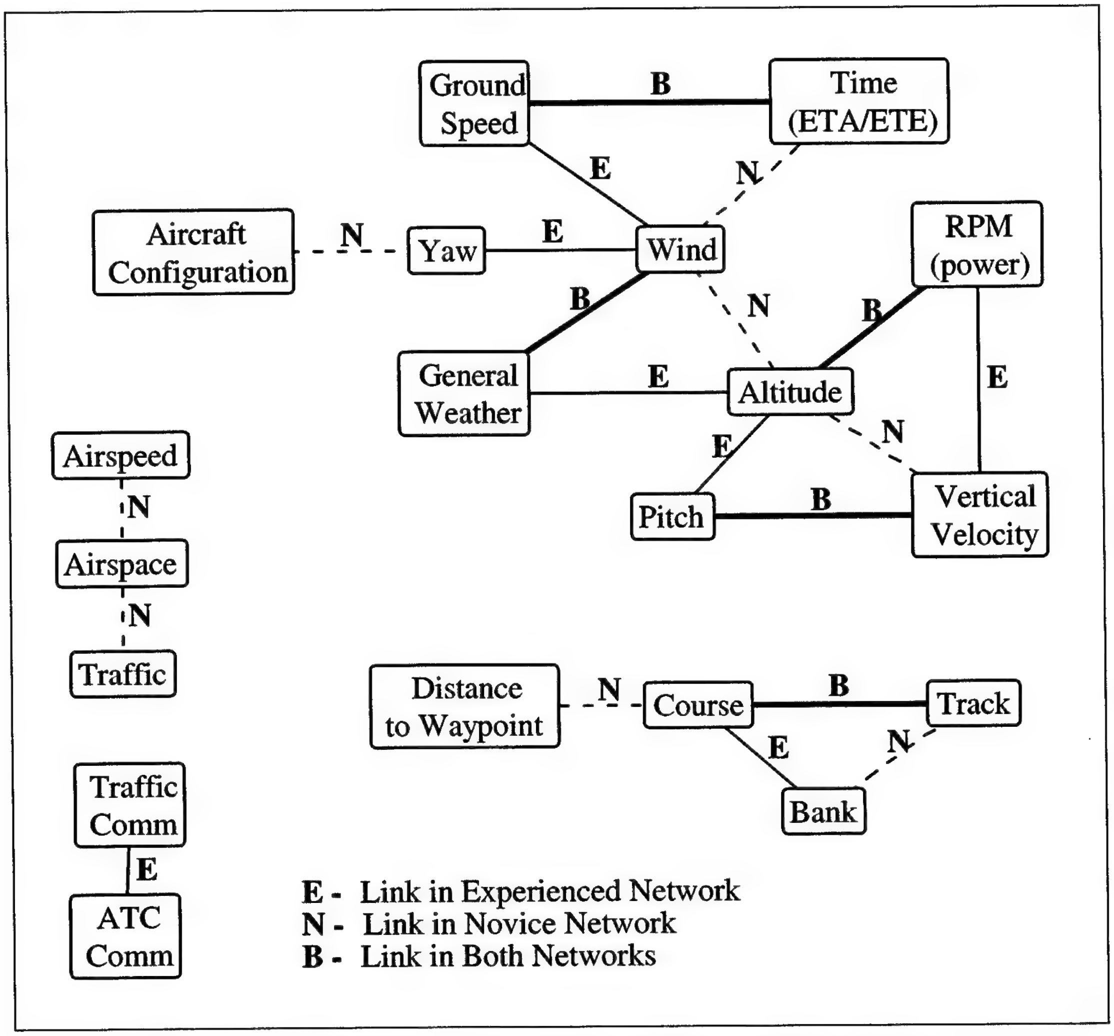

Figure 15. Differences in novice and experienced pilots' networks.

shown include the links shared by both networks to highlight the triangles. The other link differences cannot be accounted for by such triples suggesting greater differences in the perception of relatedness between the two groups of pilots.

CONCLUSIONS, APPLICATIONS, RECOMMENDATIONS, AND CAVEATS

The data presented in this report provide a picture of how information functions in the National Airspace System, including how the information is prioritized and organized by pilots. The views of information priorities show how priorities change with phases of flight and how pilot experience relates to the perception of priorities. The views of information organization reveal some of the ways pilots inter-relate the various elements of information. It is difficult to determine the extent to which the experience differences in this study are due to experience per se as opposed to selection that occurs over the flying careers of pilots. We know that pilot attrition may be due to a number of factors, ranging from choosing to stop flying to having a fatal accident. Is it that the pilots who endure have different perceptions of priorities to begin with, or do pilots learn to develop these priorities as a result of experience? It may well be that both of these factors operate. A longitudinal study would provide some answers to these questions. Regardless of how the experience issue is resolved, the data reported here should be of value in designing information display systems.

This study has focused on information priorities, information organization, and information sources. There are certainly several other factors that are important in the design of information displays, including issues of perception, format, analog vs. digital, etc. As new display solutions are sought, it is important to keep in mind the value of redundancy. Limited panel real estate places a severe constraint on just how much can be placed before the pilot, but some solution to the problem of providing alternative sources of information must be found in the interest of safety. We have not emphasized this issue in the report, but our analysis of sources using the instruments found in most general aviation aircraft shows the redundancy existing in the present system. New systems must strive to maintain redundancy to ensure pilot confidence.

There are numerous ways that data on pilot information organization and information priorities could be used to enhance the safety of operations in the national airspace. These data can potentially be used to position instrumentation in the cockpit, design integrated cockpit information systems (ICIS), restructure the logic of and displays for flight management systems (FMS), modify communications between pilots and ATC/ATM (both voice and datalink), reduce workload, and even to refine methods and curricula for flight instruction.

Instrumentation Layout and Integrated Cockpit Information Systems

Given that one has a good idea of how information elements are prioritized and related in the perception of the pilot, it should be helpful to use these findings to determine how data are presented in the cockpit in a way that would enhance processing of those data, both in terms of speed and accuracy. For example, one can see from the hierarchical clusters shown in Figure 14 that fuel status and distance to waypoint are clustered, and are closely tied to ETA/ETE and ground speed. This might lead to recommendations that displays for related parameters be closely grouped or, better yet, integrated for more effective presentation. Thus, one could argue the case that one way to facilitate data assimilation would be to present a graphic showing aircraft location on a plan-view map, with range rings or vectors indicating waypoints/destination and instantaneous "fuel" range, both absolute and with 45-minute reserve. The clustered data are now effectively presented in an integrated display that allows direct and rapid interpretation of the situation.

Flight-Management Systems

Several studies (i.e., Funk et al., 1999; Degani, Shafto and Kirlik, 1999) have found that pilots perceive flight-management systems as problematic in a number of ways. Two contributing factors to this attitude have been identified: (1) the organization and grouping, or lack thereof, of functions and data; and (2) the failure of the system to adequately communicate intent to the pilot. The first is probably the most amenable to modification using clustering/connections data, and some efforts are presently underway (Riley, DeMers, & Misiak, 1998) to restructure the data-entry interface more along the lines of natural language, aping the way in which instrument clearances are verbally delivered and read back. This, to some degree, involves a reorganization of the data in ways that are more consistent with pilot mental models and constructs. The present data can be used in such endeavors to group data for input to and retrieval from the FMS in a more natural and expected fashion, which should reduce entry times and errors.

The second problem of communicating intent may also involve restructuring reports of FMS activity in such a way as to be more easily associated, by the pilot, with the greater context of the flight. Although there is a significant argument that the best FMS should be one in which there are no modes but, rather, an apparently seamless operation from one flight regime to the next, the FMS intent still must be communicated in the context of current flight conditions (i.e., messaging priorities are likely to change from takeoff through cruise to landing, and the system should organize and present action-related data in the appropriate context and with the appropriate priority weighting).

Controller-Pilot Communications and Datalink

Our argument is that the organization of data is important across the board to achieve efficient, timely, and accurate responses by both the airborne and ground-based systems. Thus, the same groupings and organization applied to flight-control data can also be applied to many other forms of flight-related data

(e.g., Riley et al., 1998). Domain-specific analyses will be necessary, however, to verify that each of the users is receiving data in formats appropriate to their task. This should apply to data regarding weather, airports, traffic, obstacles, and clearances, to name a few.

Flight Instruction Curricula

One question that has not been addressed directly here is the issue of how data should be organized in the most abstract sense versus how data are organized. It is clear that the actual task structure (how we fly aircraft and how the data are presented as a function of aircraft certification requirements) largely determines how instruction is structured.

However, it is not at all clear that the way in which data are presently organized and presented is necessarily optimal. The question, which could be pursued here, is what organization may be imposed upon fundamental information regarding aircraft flight (rate of travel, altitude, heading, position relative to desired location in space or final goal) by nonpilots as a function of their concept of the natural environment and the inherent implied organization via physical features and properties. Cases have already been documented (Beringer, 1978) in which pilot behaviors were being established during training that were counter to nonpilot stereotype responses, leaving the door open for reversion to those now inappropriate behaviors under stress.

The same can be asked of the organization of data for the flight task: To what degree may we be distorting any inherent organizational structures that exist in the general population in subsequent flight training, and how might task and data structures be modified to take better advantage of extant knowledge?

Regardless of how these issues are resolved, flight instructors may benefit from knowing how more and less experienced pilots differ in information priorities and in the mental organization of that information.

An Example: Applying the Data to Display Allocation/Design

One specific example of how these data might be applied can be found in the design of display suites for the new GA glass cockpit, which are expected to include a Primary Flight Display PFD) and a Multifunction Display (MFD). The data demonstrate that pilots require different information sets depending on the mode of flight. Thus, it is expected that although common information may be present across two or more modes, the relative importance of the information will change. Consequently, a display-decluttering scheme should take into account the most salient pieces of data and preserve those over other less task-relevant data.

Assume, for example, that we are allocating display space in such a way that we can depict only the six highest-priority items (the assumption of display limitations is real; the choice of 6 is artificial). Concentrating on takeoff and drawing from the experienced-pilots' rankings presented in Figure 4, we would select RPM/power, wind, engine health, aircraft configuration, airspeed, and general weather for presentation. Next, we can examine Figure 14 to determine those elements that naturally cluster together and may be suited for integrated presentation. We find that airspeed and aircraft configuration cluster at a high level, with RPM/power and engine health forming another high-level cluster, with these two clusters in close proximity and with a direct link. Wind and general weather can be seen as another cluster with a link to the first (the one containing airspeed). This suggests that there could be three display subgroups derived from these data, each consisting of two data variables. The degree to which the individual pieces can be woven into an integrated presentation will, of course, affect formatting, and it should be kept in mind that the data in this report do not specifically designate a particular format. Rather, the data reveal the priority of information elements from the pilot's perspective.

One can then apply some human factors engineering in this example, however, and see that an integrated presentation of applied power or thrust that includes some status indicator depicting engine health would be a good start. [Example: A bargraph presentation showing percent thrust with color of the bargraph or texture fill indicating the status of the power plant.] Thus, one component of the display is defined. Second, a component presenting airspeed and aircraft configuration (airspeed is an index of when gear and flaps can be extended/retracted) would be a next step, with direct graphical indices or icons representing the status of gear/flaps/spoilers and somehow directly associated with the airspeed scale or indication. Finally, one could have a third representation

depicting surface wind graphically related to direction of travel (expected to be runway heading on takeoff). These elements should therefore satisfy the requirements given the restrictions assumed.

One may have the opportunity, however, to approach the display problem from the other direction given effective integration techniques and boundless display area. This approach would focus on providing all of the information elements ranked in the first two categories (1 = critical and/or frequently accessed; 2 = important and/or usually accessed). Going back to our previous example, one might then choose to include any data that achieved a ranking value of 2.5 or smaller (everything from 1's all of the time to 2's half of the time and 3's half of the time). This approach would then cause the first 22 items (as rated by experienced pilots) in Figure 4 to be included for display-system presentation (all the way down to "airport configuration"). This approach would be more suited to selecting data for the entire display suite, as opposed to selecting items for a small subset of the display system. Grouping would be pursued as previously by looking at clusters and links. Again, it should be kept in mind that the exact form of the data displays will be governed by established human factors display-formatting principles, guidelines, and ultimately the standards presently in force for the specific systems hosting the displays.

Prospectus

In this research, the emphasis has been on identifying information priorities and information organization. It would be valuable to take the work reported here as a starting point for an examination of the kind of decisions pilots make in the course of flight. In particular, the decisions could be examined from the perspective of the information that goes into the decisions. Our analysis of clusters of information elements points in that direction, but it would be informative to pursue the involvement of information in decisions in greater depth.

Finally, this research effort has focused on normal flight operations in contrast to unusual situations or emergencies. Clearly, the work is incomplete without including these situations. We are in the process of remedying this lack in a second investigation that will focus on a related analysis of information priorities in emergencies.

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APPENDIX A
Demographic Questionnaire

Aviation Research Group
New Mexico State University

1. Please estimate your logged hours in each of the following categories of aircraft:

   Single Engine Land ___________

   Multi Engine Land ___________

   Other ___________ Types ____________________

2. Please list the year in which you obtained the following ratings or certificates:

   Private Pilot ___________

   Instrument ___________

   Commercial ___________

   CFI ___________

   CFII ___________

   ATP ___________

3. Approximately how many hours have you logged in the last 12 months?___________

4. How, where, and when did you first learn to fly?

		Year	Location
___	Individual Flight Instructor	_____	____________________________
___	Civilian Flight School	_____	____________________________
___	Military Flight School	_____	____________________________
___	Other	_____	____________________________

APPENDIX B
Instructions for Priority Ratings and the Priority Rating Form

Aviation Research Group
New Mexico State University
Las Cruces, NM
Roger Schvaneveldt, Director
The Priorities and Organization of Information
Accessed by Pilots in Various Phases of Flight

Task Description

We are developing an analysis of the priorities associated with various kinds of information in various phases of flight. At present, we are focusing on the priorities for normal operations as opposed to emergencies. You will greatly assist us in this effort by providing us with your judgments of information priorities.

On the next page, you will find some questions about your experience in aviation. These data will help us compare the priorities of pilots with varying experience. On the page following is a list of the information elements along with our definitions of these elements. Study the list so you will understand what we are trying to get at with your priority ratings.

Following the list is a sheet with the information elements on the rows and phases of flight on the columns. You are to enter your priority ratings in the cells. Most pilots find it best to work down each column rating the importance of the element for that phase of flight. We have also included two planning phases: Preflight Planning and In-flight Planning. Because you can give priorities associated with planning in these two columns, please rate the importance of the information elements in the flying phases relative to flying as opposed to planning. The flying phases include: Takeoff, Climb, Transition to Cruise, Cruise, Descent, Approach, and Landing. Try to assign priority ratings that cover both IFR and VFR flights. That is, give the highest priority for the information element considering both IFR and VFR flights.

Use priority ratings as follows:

Priority	Description
1	Critical and/or Frequently Access
2	Important and/or Usually Accessed
3	Relevant and/or Sometimes Accessed
blank	Not Relevant or Rarely Accessed

If you have comments or questions, you can reach Dr. Schvaneveldt via e-mail: schvan@crl.nmsu.edu. You may also write any comments below or on the back.

Thank you very much for your assistance.

Priority Rating Form

Information Element	Preflight Planning	Takeoff	Climb	Transition to Cruise	Cruise	In Flight Planning	Descent	Approach	Landing
Aircraft configuration									
Engine health									
Fuel quantity									
Fuel selection									
RPM (power)									
Altitude - AGL									
Altitude - MSL									
Distance									
Bank angle									
Pitch (attitude)									
Yaw									
Course									
Heading									
Track									
Waypoints									
Airspeed									
Ground speed									
Vertical Velocity									
Time - ETA/ETE									
Airport configuration									
Runway aim point									
Runway remaining									
ATC Communications									
Traffic / other Comm									
Obstructions									
Traffic									
Airspace									
General Weather									
Wind									

APPENDIX C
Procedure for Collecting Relatedness Ratings

Collection of the relatedness data occurred over an eight-month period. The participants completed a demographic questionnaire (see Appendix A). After the demographic form was completed, the participants were directed to the computer for the relatedness ratings. The first screen consisted of these instructions:

> Greetings, thank you for participating in our study of the information pilots need in the course of flight. In other parts of the study, we have determined how pilots view the priorities of various elements of information in each phase of flight. Now we are trying to characterize how pilots mentally organize flight-related information. What we need from you in your judgments about how closely related the different elements of information are to each other.
>
> We will show you all the pairs of the elements listed below, and for each pair, you should enter a number from 1 to 9 indicating how related you think the two elements in each pair are. A rating of 9 indicates that two information elements are very closely related, and a rating of 1 indicates that two information elements are not very related at all. Feel free to ask if you have any questions.

The second screen gave a list of the 22 information elements (see Table 10).

The appearance of the rating task is shown in Figure 16. Ratings were selected by pressing a number key (1 to 9); the choice could be changed until the space bar was pressed when the next pair would be presented. The 231 pairs were presented in a different random order for each of the participants.

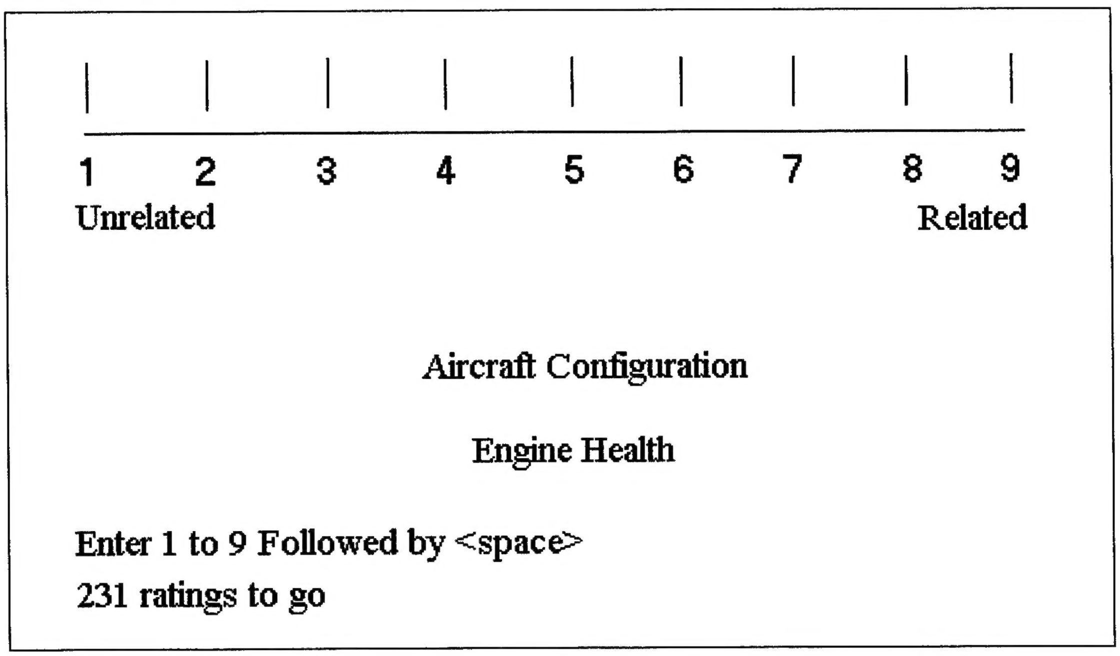

Figure 16. The Relatedness Rating Screen

The final screen presented a short debriefing:

> That's it. Thanks again for your help. We hope to contribute to improving aviation with this work. We appreciate help from pilots such as yourself to accomplish our objectives.